0048212

DOE/RL-94-95
Rev. 1

Hanford Sitewide Groundwater Remediation Strategy

United States
Department of Energy
Richland, Washington

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5285 Port Royal Road
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Printed in the United States of America

DISCLM-5.CHP (8-91)

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Date Published
September 1997

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

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EXECUTIVE SUMMARY

This document fulfills the requirements of the *Hanford Federal Facility Agreement and Consent Order*, Milestone M-13-81 (Ecology et al. 1989), to develop a concise statement of strategy that describes how the Hanford Site groundwater remediation will be accomplished. The strategy addresses objectives and goals, prioritization of activities, and technical approaches for groundwater cleanup.

The strategy establishes that the overall goal of groundwater remediation on the Hanford Site is to restore groundwater to its beneficial uses in terms of protecting human health and the environment, and its use as a natural resource. The Hanford Future Site Uses Working Group (HFSUWG 1992) established two categories for groundwater commensurate with various proposed land uses: (1) restricted use or access to groundwater in the Central Plateau and in a buffer zone surrounding it and (2) unrestricted use or access to groundwater for all other areas.

In recognition of the Hanford Future Site Uses Working Group and public values, the strategy establishes that the sitewide approach to groundwater cleanup is to remediate[1] the major plumes found in the reactor areas that enter the Columbia River and to contain the spread and reduce[2] the mass of the major plumes found in the Central Plateau. Specifically, for the reactor areas, the following plumes are to be remediated: strontium-90 in the 100-N Reactor area, and chromium

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[1] Groundwater remediation refers to the reduction, elimination, or control of contaminants in the groundwater or soil matrix to restore groundwater to its intended beneficial use.

[2] Containment and mass reduction refers to controlling the movement of groundwater contamination for the purpose of treatment.

in the 100-K, 100-D, and 100-H Reactor areas. In the Central Plateau, an initial approach of containment and mass reduction is taken for the organic contamination associated with Plutonium Finishing Plant past operations and the combined technetium-99 and uranium plumes associated with the Uranium-Trioxide Plant. Other minor plumes exist on the Hanford Site that will be addressed in a manner similar to the major plumes dependent upon their location, extent, and the threats posed by the contaminants. Because of the relatively minor impacts of these plumes, they are not the focus of this document.

The approach to remediate each major plume is presented. Each approach is based on the general remediation principles to (1) define the extent of contamination, (2) identify and gain control of continuing sources of contamination, and (3) implement containment/remediation of the plumes. Major information needs were revealed, including the following: in the 100 Areas, the geographic extent of chromium contamination at the 100-D and 100-K Reactors, and the method to control the source of strontium-90 contamination at 100-N Reactor; in the 200 West Area, the vertical distribution of organic, uranium, and technetium-99 contamination; and in the 200 East Area, the extent and source of technetium-99 and cobalt-60 contamination.

A coordinating group is proposed to provide continuing direction, adjust priorities, and respond to new information as it is developed. Cleanup is presented as a phased process consisting of expedited, interim, and final actions. Succeeding phases of remedial actions are oriented toward implementing the record of decision that, in turn, will satisfy broader cleanup objectives than found in the initial approach presented here.

The reduction of operations-derived liquid effluent to the soil is deemed an integral element of this document. Protecting the Columbia River, reducing the spread of contamination, maintaining a bias for action, and using available technology are all public values that are recognized in the strategy and incorporated into the approaches. Qualitative estimates of technical feasibility are incorporated into the remediation approach described for each plume.

Nitrate, tritium, and iodine-129 plumes contaminate wide areas of the aquifer under the Hanford Site. The strategy identifies the need for a detailed evaluation of practicable methods to reduce the flux of nitrate and tritium to the Columbia River and to control the continued spread of iodine-129.

Key regulatory issues must be resolved to accelerate remediation, e.g., criteria for discharging treated groundwater back to the soil. This treated groundwater, from which the primary contaminants have been removed, may still contain elevated levels of cocontaminants[3]. Additional treatment for cocontaminants is identified as a major factor in determining the scope and feasibility of many of the groundwater cleanup projects on the Hanford Site.

Groundwater remediation will affect portions of the existing monitoring well networks. These effects must be identified and resolved. Refinement of the existing monitoring networks and better coordination with the monitoring effort of the groundwater remediation is needed to better

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[3] Cocontaminant refers to those chemical species and radionuclides that are found in addition to the contaminants of primary concern.

define the extent of plumes, their movement, and the effect of cleanup on groundwater contamination.

The strategy identifies the following areas of technology development that may significantly improve cleanup: barriers to flow, dense nonaqueous phase liquid identification and recovery, stabilization methods, and improved ion-specific water treatment methods. Furthermore, the strategy identifies the strontium-90, cesium-137, and plutonium contamination identified with the B-5 reverse well as a potential area for technology demonstration.

This remediation strategy is an integral part of the *Hanford Site Groundwater Protection Management Program* (DOE-RL 1995a). Coordination of groundwater remediation within the broader Hanford Site program of groundwater protection is necessary. Continuing the development and evaluation of contingency cleanup strategies is needed should the existing approaches prove infeasible.

This strategy establishes an approach to remediation that emphasizes early and aggressive field programs while simultaneously collecting and evaluating information leading to a final record of decision. This strategy also defines a decision process to aid in planning the remedial activities that lead to selection and implementation of final remedies. The approaches will be refined as the remediation proceeds and a record of the cleanup results develops. The development of site- and contaminant-specific groundwater remediation goals and final remediation alternatives remains a product of risk assessment, technical feasibility, and cost considerations. The development of this information remains at the operable unit level.

Refinement of the strategy will be the responsibility of a U.S. Department of Energy, Richland Operations Office-chaired group consisting of both internal and external groups, including stakeholders who play a role in liquid effluent management and cleanup activities at the Hanford Site. The Environmental Restoration Contractor, with support from the Management and Integration Contractor for the U.S. Department of Energy, has the primary responsibility to carry out the strategy.

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ACRONYMS

ACL	alternate concentration limit
ARAR	applicable or relevant and appropriate requirement
CCL_4	carbon tetrachloride
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
CMS	corrective measure study
DCE	1,2 dichloroethylene
DOE	U.S. Department of Energy
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
ETF	Effluent Treatment Facility
FFS	focused feasibility study
FS	feasibility study
GPMP	*Groundwater Protection Management Plan*
HPPS	*Hanford Past-Practice Strategy*
IRM	interim remedial measure
IROD	interim record of decision
MCL	maximum contaminant level
MTCA	*Model Toxics Control Act*
RA	remedial action
RCRA	*Resource Conservation and Recovery Act of 1976*
RI	remedial investigation
RL	Richland Operations Office
ROD	record of decision
TEDF	Treated Effluent Disposal Facility
TCE	trichloroethylene
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TSD	treatment, storage, and/or disposal
WAC	*Washington Administrative Code*

1.0 INTRODUCTION

1.1 PURPOSE

This document establishes the basis for managing remediation of contaminated groundwater at the Hanford Site. The strategy is an integral part of the refocused environmental restoration program. This document provides the following:

- Direction for developing sitewide cleanup objectives for groundwater remediation
- A basis for informed decision making and future planning related to groundwater remediation
- A means to prioritize cleanup actions to optimize technical, administrative, and financial resources for effective remediation of groundwater
- A means for facilitating involvement of the stakeholders.

A sitewide perspective is used to describe the strategy. Contamination problems are discussed at a broad, geographic scale and reflect the major groundwater issues facing the U.S. Department of Energy (DOE). Current stakeholder values as well as existing *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1989) milestones are incorporated in the strategy. Future groundwater remediation milestones will be an outgrowth of this strategy. Key technical, institutional, and regulatory issues are identified.

This strategy provides direction to decisions affecting sitewide cleanup. Determination of operable unit-specific remediation goals (applicable or relevant and appropriate requirements [ARAR]) should reflect this strategy. However, interim and final remediation goals are site specific and will be developed at the operable unit level.

Since the publication of Revision 0 of this document, the DOE-Richland Operations Office (RL) has performed new work to support refinement of the sitewide groundwater remediation strategy. This work consists of the following elements:

- Modeling the major plumes on a sitewide basis to predict contaminant migration over the next 200 years
- Developing a decision process to support future remediation planning leading to final remedy decisions
- Developing a groundwater monitoring strategy to streamline the current programs for greater cost effectiveness.

This revision of the document incorporates the results of these activities. This document is being incorporated into the *Hanford Site Groundwater Protection Management Plan* (GPMP) (DOE-RL 1995a).

1.2 CONTEXT FOR STRATEGY DEVELOPMENT

More than 220 km^2 (85 mi^2) of groundwater beneath the 1,450-km^2 (560-mi^2) Hanford Site is contaminated by hazardous and radioactive waste to levels above federal drinking water standards (DWS) (40 *Code of Federal Regulations* [CFR] 141) and Washington State groundwater quality criteria (*Washington Administrative Code* [WAC] 173-200). Restoring the groundwater resource beneath the Hanford Site, reducing contaminant transport offsite via the groundwater pathway, and understanding the risks posed by contamination are all objectives of the environmental restoration program. Groundwater remediation at the Hanford Site is likely to be a complex, long-term, and potentially costly endeavor.

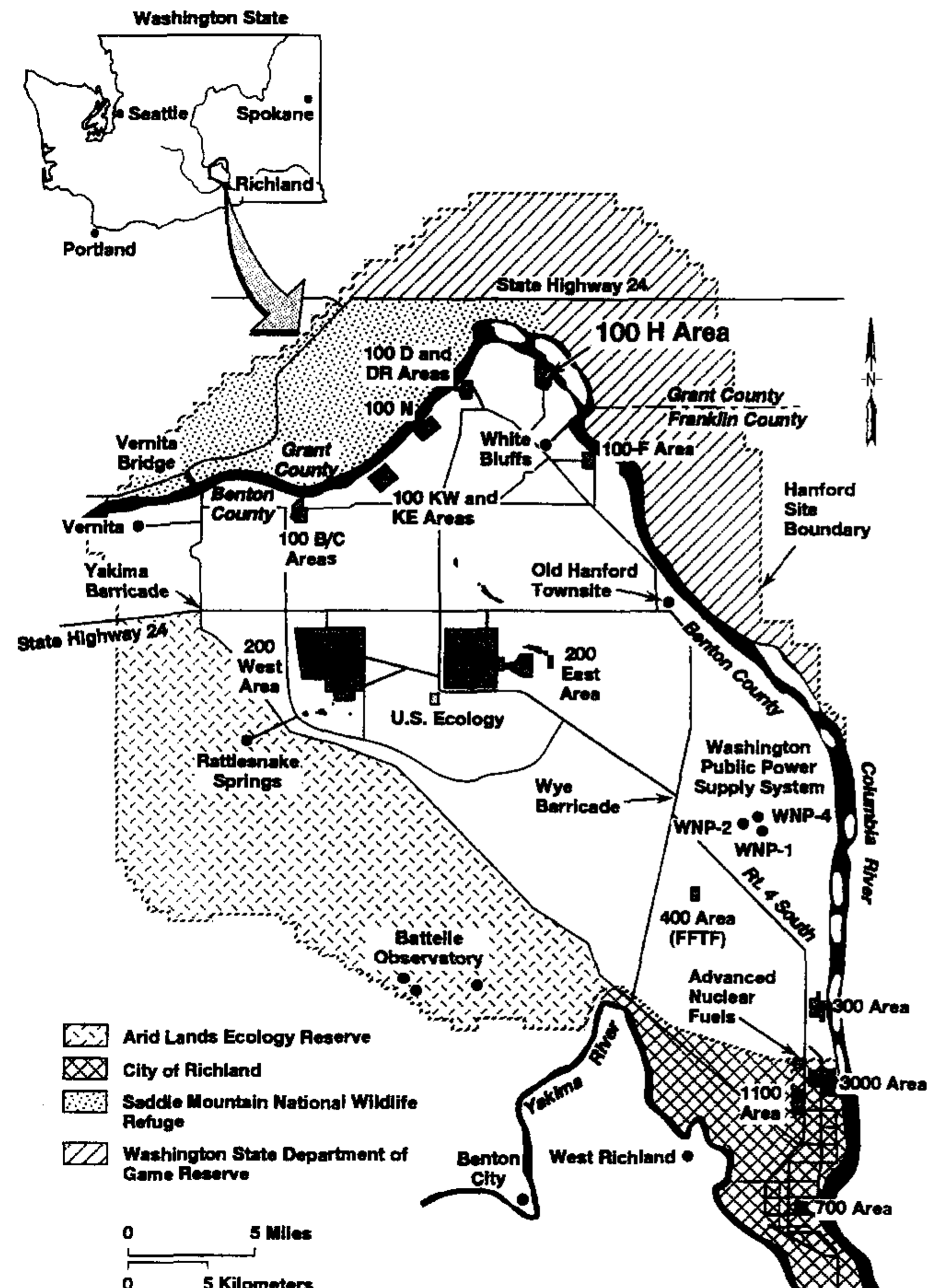
Contamination affects a substantial volume of groundwater, which ultimately discharges to the Columbia River. The public has expressed a high degree of interest in the consequences of this discharge and the outcome of the efforts to protect this valuable resource. Cleanup control and direction are established under the Tri-Party Agreement (Ecology et al. 1989). This agreement between the DOE, the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) is legally binding for the DOE and is enforceable by the Ecology and the EPA.

The magnitude of the environmental restoration challenge is revealed by the number of hazardous substance release sites. The Hanford Site has been subdivided into four subareas that are included on the National Priorities List (40 CFR 300, Appendix B) of hazardous substance release sites. These subareas contain over 1,000 past-practice sites subject to cleanup under either the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) or the *Resource Conservation and Recovery Act of 1976* (RCRA). These sites have been grouped into over 75 operable units and eight geographic regions and specific facilities. A location map showing the commonly cited names of operational areas is presented in Figure 1-1.

For convenience, CERCLA terminology is used almost exclusively throughout this document to describe processes, strategies, and documentation. The terminology, documentation, and administrative processes for RCRA may be different than for CERCLA. However, the technical elements of the strategy are applicable to both RCRA and CERCLA past-practice operable units.

As environmental restoration progresses from the assessment phase to active cleanup, it is essential to maintain a balanced and consistent approach. The large number of individual remediation decisions and cleanup activities poses a substantial challenge to the DOE, state and federal regulators, and the contractors performing the work. Furthermore, it is evident that the outcome of remediation for a particular operable unit may be dependent on actions taken at other operable units within the same groundwater flow system. Thus, the need for a comprehensive, sitewide groundwater remediation strategy has been recognized and included as Tri-Party Agreement Milestone M-13-81 (Ecology et al. 1989). This update to the previous strategy describes how groundwater cleanup will be conducted at the Hanford Site and includes objectives, goals, and the technical approaches to address each major plume.

Figure 1-1. Hanford Location Map.



2.0 INSTITUTIONAL AND REGULATORY FRAMEWORK FOR REMEDIATING GROUNDWATER

This chapter describes the institutional and regulatory framework in which groundwater remediation is to be implemented under CERCLA. A unique process for applying CERCLA actions has evolved due to the complexity of administrating cleanup for the large number of individual operable units at the Hanford Site. Other important programs at the Hanford Site that have a bearing on groundwater cleanup are also summarized in this section.

2.1 TRI-PARTY AGREEMENT

In May 1989, the EPA, Ecology, and DOE entered into an interagency agreement, the Tri-Party Agreement (Ecology et al. 1989). The Tri-Party Agreement provides the legal and procedural basis for cleanup and regulatory compliance at the numerous hazardous waste sites on the Hanford Site. It identifies time tables for waste cleanup and a series of "milestones" by which certain actions must be implemented or completed.

The Tri-Party Agreement coordinates two important regulatory programs: RCRA and CERCLA. The EPA has the lead role in administering CERCLA. Four subareas of the Hanford Site, the 100, 200, 300, and 1100 Areas, are included on the EPA's National Priorities List (40 CFR 300, Appendix B).

Ecology has the lead role in administering RCRA under provisions of Washington State's WAC 173-303, "Dangerous Waste Regulations." Under the Tri-Party Agreement, there are more than 50 RCRA treatment, storage, and/or disposal (TSD) units that will be closed or permitted to operate. Most of the TSDs are located within operable units.

2.2 APPLICABILITY OF SITEWIDE GROUNDWATER REMEDIATION STRATEGY

This document provides a means of addressing issues of sitewide significance, and a broader perspective for planning remediation at the operable unit level. Future Tri-Party Agreement milestones will be developed on the basis of this strategy (Ecology et al. 1989). Decision making at the operable unit level is driven by regulations and should be compatible with the strategy outlined in this document. Figure 2-1 illustrates the relationship of the groundwater remediation strategy to the *Hanford Past-Practice Strategy* (HPPS) (DOE-RL 1991).

2.3 CERCLA REMEDIAL INVESTIGATION/FEASIBILITY STUDY PROCESS FOR THE OPERABLE UNIT

Within this document, groundwater remediation refers to those CERCLA and RCRA past-practice restoration activities that return contaminated groundwater to its beneficial uses wherever practicable. Potential beneficial uses of groundwater are (in part) dependent on the quality of the resource. In general, restoration cleanup levels in the CERCLA program are established by ARARs, which include the substantive requirements of RCRA where applicable. Most of the past-practice groundwater operable units are being addressed under CERCLA, but two are currently being addressed under RCRA corrective action authority. As discussed in Section 1.2, for convenience in avoiding repetitious text, CERCLA terminology and processes are used throughout this strategy document and should be understood to apply to both RCRA and CERCLA even though the terminology and administrative processes of RCRA may differ from CERCLA.

The CERCLA regulatory process typically involves establishing preliminary remediation goals for individual operable units, which are modified on the basis of the remedial investigation (RI) and feasibility study (FS). Preliminary remediation goals for operable units are based on readily available information and ARARs. Goals may be modified as characterization and cleanup activities are implemented. However, final remediation goals are determined when specific remedies are selected and a record of decision (ROD) is reached. Preliminary and final remediation goals are generally numeric and are set at the operable unit level.

A significant portion of the effort in reaching a ROD leading to implementing remedial actions (RA) occurs under the RI and FS process. The RI is a process to determine the nature and extent of the problem represented by the release. The RI emphasizes data collection and site characterization and is generally performed concurrently and in an interactive fashion with the FS. The RI includes sampling and monitoring, as necessary, and the gathering of sufficient information to determine the necessity for RA, and to support the evaluation of remedial alternatives. The RI and the FS are collectively referred to as the RI/FS.

An FS develops and evaluates options for RA. The FS emphasizes data analysis using data gathered during the RI. The RI data are used in the FS to define the objectives of the response action, to develop remedial alternatives, and to undertake an initial screening and detailed analysis of the alternatives. Each alternative (viable approach to an RA) is assessed with respect to the following set of evaluation criteria:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost
- State acceptance

- Community acceptance.

Risk assessment evaluations are incorporated into the decision process at this time.

Once the RI/FS is completed, the EPA in conjunction with Ecology selects the appropriate cleanup option. This important step is documented by a ROD. Following the ROD, the remedial design is the technical analysis that follows selection of a remedy and results in detailed plans and specifications for implementation of the RA. An RA follows the remedial design and involves actual construction or implementation of a cleanup. A period of operation and maintenance may follow RA activities.

2.4 HANFORD PAST-PRACTICE STRATEGY

The HPPS (DOE-RL 1991) was developed for the purpose of streamlining the past-practice corrective action process. Although investigations and studies remain important for meeting long-term goals, a significant portion of the near-term funding resources can be dedicated to that remedial work for which there is sufficient information to plan and implement interim measures. The HPPS allows for the following:

- Accelerating decision making by maximizing the use of existing data

- Undertaking expedited response actions (ERA) or interim remedial measures (IRM), as appropriate, to either remove threats to human health and welfare and the environment; or to reduce risk by reducing toxicity, mobility, or volume of contaminants.

There are three paths for decision making under the HPPS. A limited field investigation refers to the collection of limited additional site data that are sufficient to support a decision on conducting an ERA or an IRM. An ERA may be implemented for situations requiring an immediate onsite response action to abate a threat to human health or welfare or the environment. For situations in which extensive information may not be necessary to initiate some cleanup action, an IRM may be implemented before a final remediation action.

2.5 OTHER RELEVANT DOE PROGRAM ACTIVITIES

Several other ongoing programs at the Hanford Site relate to or affect groundwater and are described in the following sections. Planning and implementation of CERCLA groundwater remediation should be integrated with these other DOE program activities.

2.5.1 Groundwater Protection Management Plan

In accordance with DOE Order 5400.1, *General Environmental Protection Program*, the *Hanford Site Groundwater Protection Management Plan* (DOE-RL 1995a) has been formulated. The intent of this plan is to protect the groundwater resources of the Hanford Site. With several

DOE programs (e.g., waste management, environmental protection, and environmental restoration) engaged in activities that affect groundwater, there are circumstances where coordination of these programs is necessary to prevent duplication of effort, resolve potentially conflicting objectives, and make optimal use of resources.

In January 1994, a new Tri-Party Agreement milestone, M-13-81A, was negotiated. This milestone stipulates the revision of the existing Hanford Site GPMP document (DOE-RL 1995a) to incorporate cleanup goals, Tri-Party Agreement requirements concerning discharge to the ground, groundwater withdrawal and treatment, and the treatment of liquid effluent discharged to the soil column. This document is now an integral part of the GPMP defining the approach to address current groundwater contamination problems. The revised GPMP is used to coordinate these efforts and to manage Hanford Site groundwater resources.

2.5.2 RCRA Waste Management Facilities

Under the direction of DOE-RL, there also is a major effort to comply with EPA and state regulatory requirements at TSD units. The RCRA program involves application for permits to operate regulated TSD units, compliance monitoring of groundwater to detect and assess possible contamination from the TSD units, and corrective measures including development of TSD closure plans and cleanup actions. Groundwater monitoring at a TSD facility is designed to distinguish upgradient groundwater conditions from conditions downgradient of the TSD (DOE-RL 1994a). Groundwater remediation activities that involve pumping and reintroducing treated groundwater will affect groundwater flow and quality, and will have significant impacts on portions of the RCRA monitoring program. These impacts need to be identified and resolved.

2.5.3 Liquid Effluent Program

In December 1991, Ecology and DOE signed Consent Order No. DE 91NM-177, also known as the Liquid Effluent Consent Order. The Consent Order, together with Tri-Party Agreement Milestone M-17-00, commits the DOE to an aggressive schedule for completion of effluent disposal facility upgrades and to secure permits. Under this order, permits administered for WAC 173-216, "State Waste Discharge Permit Program," requirements are applicable to certain liquid effluent streams (Ecology and DOE 1992). The Permit (WAC 173-216) requires best available technology or all known and reasonable methods of prevention, control, and treatment for those waste streams. As directed by Ecology and DOE (1992) and the Tri-Party Agreement (Ecology et al. 1989), for interim compliance purposes, groundwater impact assessments were performed for a number of effluent disposal facilities (Tyler 1991). Most of these disposal facilities are also located in CERCLA operable units.

Under DOE-RL, a liquid effluent program is being conducted to bring facilities that discharge liquid effluent into compliance with environmental regulations. The focus is to reduce liquid effluent volumes generated, expand and improve treatment capacities, and cease discharge of contaminated effluent to the ground. These efforts to reduce effluent discharges will lead to reducing the rate of spread of many contaminants, most notably beneath the 200 West Area.

The DOE-RL has constructed the 200 Areas Effluent Treatment Facility (ETF) to provide effluent treatment and disposal capability for the central plateau. The initial mission of the 200 Areas ETF (Project C-018H) is to provide treatment of process condensate from the 242-A Evaporator. Treated effluent from the 200 Areas ETF is disposed to a crib-type discharge facility called the State-Approved Land Disposal Site, which is being constructed north of the 200 West Area. A second liquid effluent program project, the 200 Areas Treated Effluent Disposal Facility (TEDF) (Project W-049H), provides a network of piping in both the 200 East and 200 West Areas. The 200 Areas TEDF discharges the treated effluent to a new pond located east of the 200 East Area.

Disposal of treated effluent from these facilities to the ground will likely result in some localized changes in groundwater flow directions. Of greater significance to groundwater remediation is the presence of potentially high concentrations (maximum 6,000,000 pCi/L) of tritiated water in the treated effluent to be disposed to the soil column from the 200 Areas ETF. Tritium cannot be practically removed by treatment (DOE-RL 1994b, 1995b). This will result in the introduction of a new tritium contaminant plume to the unconfined aquifer.

2.5.4 Operational and Sitewide Monitoring

Operational groundwater monitoring and sitewide surveillance monitoring of groundwater have been conducted by the DOE for a number of years. Operational monitoring is oriented toward evaluating the effects of operational facilities (mostly related to liquid effluent disposal) on "near-field" groundwater conditions, but also examines resultant sitewide effects of operations (Johnson 1993). The sitewide program is a broad monitoring effort primarily oriented toward evaluating "far-field" sitewide conditions and offsite exposure to Hanford Site activities (Woodruff and Hanff 1993).

2.5.5 Hanford Remedial Action Environmental Impact Statement

The DOE has interpreted the *National Environmental Policy Act of 1969* requirements to be applicable to environmental restoration program activities. The Hanford Remedial Action Environmental Impact Statement is being prepared and will examine remediation alternatives and decisions germane to overall cleanup of the Hanford Site.

2.6 REGULATORY OVERLAP

Several federal and state regulations are applicable to activities affecting groundwater. Because these regulations are applied to facilities and activities often situated in the same location, there are overlapping regulatory programs with potentially conflicting requirements and conditions to be satisfied. Some of the issues raised by this overlap of regulatory programs are described below.

- Liquid effluent disposed under a WAC 173-216 permit (Washington State regulation used to permit liquid discharges to surface and/or groundwater) may affect groundwater quality or movement in a manner that is incompatible with CERCLA remediation objectives. For example, the 200 Areas ETF (Project C-018H) disposes treated waste containing tritiated effluent to the State-Approved Land Disposal Site and, as a result, there will be a new tritium plume contaminating the unconfined aquifer.

- RCRA "derived-from" and "mixture" rules for listed waste as administered by Ecology under WAC 173-303 could result in additional regulatory requirements for CERCLA cleanup actions. This could delay the start of remediation efforts if substantive requirements of RCRA are imposed. However, the rules contain provisions for waivers of such requirements if they can be justified.

Effective and expedient implementation of groundwater remediation depends on clarification and resolution of potentially conflicting regulatory issues.

2.7 GROUNDWATER MONITORING NETWORKS

Existing Hanford Site monitoring networks were not designed to meet the needs of the environmental restoration mission. The RCRA and operational monitoring networks and CERCLA groundwater investigations are typically designed to evaluate groundwater conditions at individual facilities or in a limited geographic area. Implementing multiple, concurrent groundwater remediation efforts will affect large areas and impact many of the localized networks, significantly reducing their effectiveness.

To support the refocused environmental restoration program, it is recommended that a monitoring network be developed based mostly on existing wells that address the following:

1. The effectiveness of RAs
2. The movement of plumes
3. Early notification of increasing contamination
4. Compliance with selected standards in areas away from the plumes.

Coordination of groundwater data collection among the systems is required to maintain an efficient, cost-effective operation.

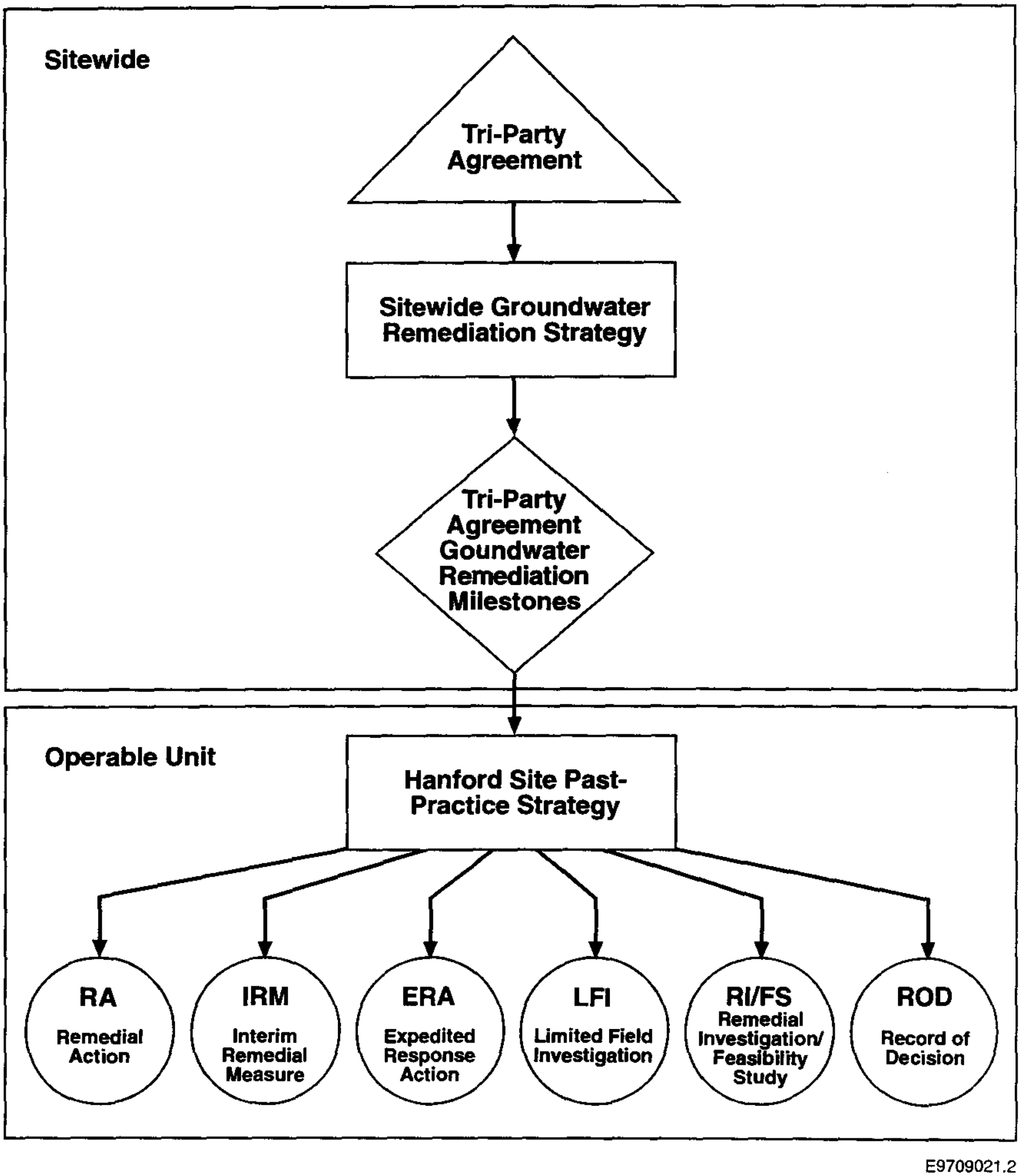
To better align with the regulatory framework of remediation, the monitoring network should consist of four categories of monitoring wells:

- Monitoring to ensure protectiveness (area periphery wells)
- RA assessment wells
- Characterization monitoring wells
- Compliance monitoring wells (RCRA TSD and past-practice waste sites).

A remediation effort would include wells that fit each category; e.g., nesting from centers of highest contaminant concentrations (RA wells), to lower concentration (area periphery wells), to areas of no contamination (compliance wells). The area of coverage for each well category, sampling, and reporting requirements would be established to meet the objectives of the well category.

Additional details of a sitewide monitoring strategy are given in Section 5.13.

Figure 2-1. Relationship of the Statewide Groundwater Remediation Strategy to the Hanford Site Past-Practice Strategy.



3.0 STAKEHOLDER VALUES TO GUIDE REMEDIATION

Successful remediation of groundwater necessitates public, tribal, and regulatory acceptance of both the process and outcome. That acceptance is more likely to occur when an informed public is provided meaningful opportunities to participate in the process and help determine the outcome. This strategy was developed with recognition that stakeholder values should shape cleanup objectives and aid in prioritizing the sequence of cleanup actions. While there is a great diversity of viewpoints among the stakeholders in cleanup of the Hanford Site, there are values shared by many that may serve as themes for building consensus and providing direction to groundwater remediation. It is necessary to have a vision for what must be accomplished in the cleanup of the Hanford Site. The desired future uses for the land and resources of the Hanford Site provide the basis for determining the goals of environmental restoration. This section presents stakeholder values and describes proposed future uses of the Hanford Site.

3.1 VALUES

Values to guide groundwater remediation are based on comments and statements expressed by the public, Indian Tribal Nations, and stakeholders in a variety of public forums. Initial information for this section was derived primarily from public commentary to recent revisions of Tri-Party Agreement milestones (Ecology et al. 1989), from Hanford Site cleanup stakeholders and Indian Tribal Nations that participated in the Hanford Future Site Use Working Group (HFSUWG 1992), and the Hanford Tank Waste Task Force (Tank Waste Task Force 1993). Subsequent refinement of this document will incorporate, as appropriate, public and Indian Tribal Nation perspectives expressed during workshops for groundwater remediation and the Hanford Advisory Board perspectives.

Commonly held values to guide groundwater remediation are as follows:

- Protect human health, worker safety, and the environment
- Protect the Columbia River
- Use available technology and start remediation
- Develop new technologies to clean up contaminants less amenable to remediation with available technologies
- Reduce the mobility, toxicity, and quantity of groundwater contaminants
- Do nothing to make groundwater protection and remediation efforts less effective
- Comply with applicable federal, state, and local laws/regulations, and Indian Tribal Nation treaty rights

- Eliminate the disposal of liquid waste to the soil column
- Clean up groundwater on a geographic basis, to the level necessary to enable the future land use option to occur
- Facilitate the efforts by DOE to relinquish control of parts of the Hanford Site
- Use funding wisely and effectively
- Minimize the amount of land area that will be impacted by waste management efforts
- Reintroduce treated and partially treated groundwater to the aquifer only in areas already contaminated.

3.2 EXTENT OF CLEANUP TO ENABLE FUTURE USES

For the purpose of identifying a range of potential future uses for the Hanford Site, the Future Site Uses Working Group was convened (HFSUWG 1992). The group was composed of representatives from relevant federal, Indian Tribal Nations, state, and local governments, as well as representatives from constituencies for labor, environmental, agricultural, economic development, and citizen interest groups, all with an interest in the cleanup and future uses of the Hanford Site. Generic proposals for how an area of the site might be used in the future, called "future use options" were developed. The following types of future use options were considered:

- Agriculture
- Wildlife
- Indian Tribal Nation (Native American) uses
- Industry
- Waste management
- Research/office
- Recreational/related commercial
- Recreation.

In devising cleanup scenarios for the various future use options, the group addressed the issue of "how clean is clean." Cleanup scenarios identify distinct levels of access necessary to allow various future land use options, which are based on the presence of contamination to the air, surface, subsurface, and groundwater. Potential beneficial uses for groundwater are therein linked to future use options. The following levels of access were defined by the group:

- Exclusive--an area where access is restricted to personnel who are trained and monitored for working with radioactive or hazardous materials

- Buffer--the part of the Hanford Site that surrounds an exclusive area. It is treated like an exclusive area because of potential risks from the exclusive area, in which environmental restoration activities (but not waste management area activities) may occur

- Restricted--an area where access is limited because of contamination, with the exception that the groundwater may be restricted on an interim basis and ultimately cleaned up to unrestricted status

- Unrestricted--an area where there is no access restriction.

3.3 CLEANUP SCENARIOS AND PRIORITIES

The Future Site Use Working Group devised cleanup scenarios for six geographic study areas (Figure 3-1). The group then recommended general priorities or criteria that could be considered for focusing cleanup activities. Cleanup scenarios relevant to groundwater remediation are presented in the following sections.

3.3.1 Reactors on the Columbia River

The reactors on the Columbia River area are an aggregation of all 100 Area operable units and includes reactors and associated facilities within a 68.8-km^2 (26.6-mi^2) area. For all cleanup scenarios, groundwater would be remediated to an unrestricted status for the entire area. Cleaning up contaminated groundwater flowing into the Columbia River is the most immediate and highest priority. Both the Hanford Advisory Board and the Hanford Future Site Uses Working Group have established this area as a priority for cleanup activities. The following specific areas are identified as the most important for cleanup of groundwater:

- 100-N Reactor area with associated springs and seeps
- 100-K Basins
- Groundwater contamination flowing into the Columbia River.

3.3.2 Central Plateau

The Central Plateau encompasses approximately 116 km^2 (45 mi^2) at the center of the Hanford Site and includes the 200 East and 200 West Areas and an area informally known as the 200 North Area. The cleanup scenario for the Central Plateau assumes that future use of the surface, subsurface, and groundwater in and immediately surrounding the Central Plateau would be as an exclusive waste management area. Surrounding the exclusive area would be a temporary surface and subsurface buffer zone to reduce risks associated with ongoing activities in the Central Plateau. Environmental restoration, but not waste management activities, would occur in the buffer zone to clean up existing contamination. The cleanup target for the buffer zone is to remediate and restore contaminated areas (including groundwater) for ultimate availability for unrestricted use.

For the exclusive zone, the cleanup target is to reduce risk outside the zone sufficient to minimize the size of the buffer zone or restrictions posed by contaminants coming from the Central Plateau. Periodically, the size of the buffer zone would be decreased commensurate to the decrease in risks associated with waste management activities. It is important that cleanup efforts seek to prevent the spread of groundwater contaminants to other areas of the Hanford Site. Localized groundwater cleanup within the Central Plateau should be quickly pursued for those actions that prevent the migration of contamination. In the foreseeable future, the waste management area would remain an exclusive zone. Depending on technical capabilities, it is desirable to ultimately achieve cleanup sufficient to allow future uses other than waste management.

3.3.3 Columbia River

A total of 82 km (51 mi) of the Columbia River flows through or borders the Hanford Site. Cleanup of contaminated groundwater that discharges into the Columbia River is an immediate priority. Cleanup of sediments in the Columbia River or of contaminants in the riparian zone should be undertaken only if the cleanup can occur without causing more harm than good. There should be no dam construction or dredging in the Hanford Reach. Class A water quality should be maintained over the long term, with reasonable efforts to improve the water quality over time.

3.3.4 North of the River

The "North of the River" (Wahluke Slope) subarea refers to 363 km^2 (140 mi^2) of land north of the Columbia River that is relatively undisturbed or is returning to shrub-steppe habitat. Potential uses of the subarea north of the river would be unrestricted and would not be constrained by the presence of contamination on the surface or in the groundwater. It is assumed that cleanup can be performed relatively quickly and at a low cost using existing technology; i.e., cleanup could begin immediately. This priority for early cleanup should not detract from cleaning up areas that pose an imminent health risk. It was also assumed that cleanup costs for this area are a relatively small percentage of the overall cleanup budget. Early cleanup would allow conversion of the site to future use options and show tangible progress in cleanup.

3.3.5 Arid Lands Ecology Reserve

The Arid Lands Ecology Reserve is 311 km^2 (120 mi^2) of a relatively undisturbed habitat/wildlife reserve south of Highway 240 and west of the Yakima River. Use of groundwater would be restricted where groundwater is contaminated or where withdrawal of groundwater would spread contamination. No future use options for the Arid Lands Ecology Reserve require the use of the groundwater beneath that area. Following DOE direction, cleanup of the Arid Lands Ecology Reserve has been completed.

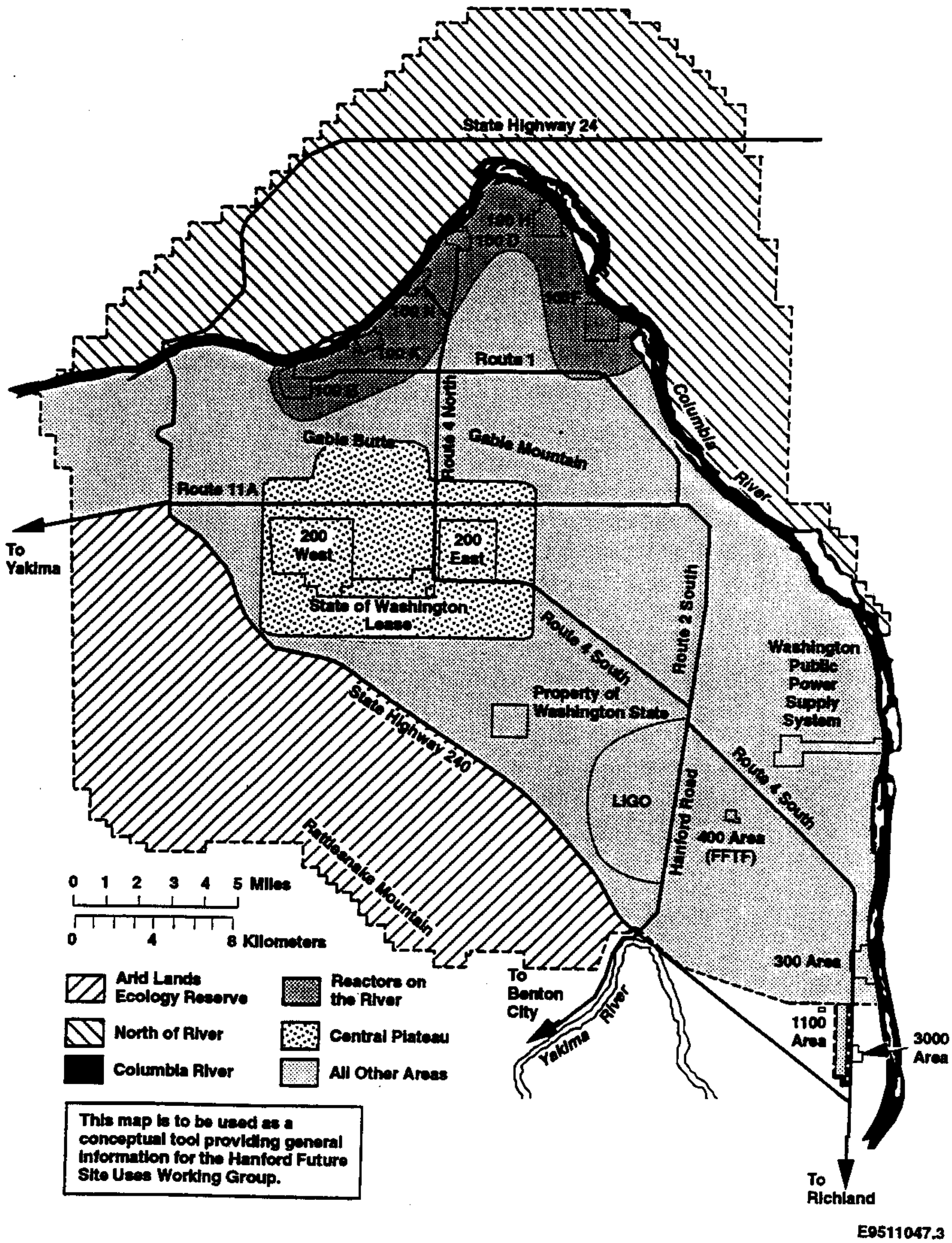
3.3.6 All Other Areas

This geographic area of 627 km^2 (242 mi^2) incorporates the 300, 400, and 1100 Areas and all of the Hanford Site not included in the five other geographic areas described by the group. Future use options defined for "all other areas" assume no migration of contaminants from the Central Plateau, except existing groundwater plumes. Key cleanup priorities would be threats to drinking water supply well fields and areas where there is existing public access to the river. Where cleanup activities would threaten wildlife species and/or habitat, the benefits of groundwater remediation should be compared to the potential harm. The guiding principle is to "do no harm."

Two cleanup scenarios were proposed. For one scenario, groundwater beneath the 1100 Area would be unrestricted, because of the proximity to the city of Richland's water supply well fields and residential areas. Elsewhere, groundwater use would be restricted where it is contaminated or where withdrawal of groundwater would spread contamination.

The second scenario suggests that access to groundwater within the 300 Area should be restricted and the other areas remediated to unrestricted status. Within 100 years of the decommissioning of waste management facilities and closure of waste disposal areas, after which it is assumed that there would no longer be institutional controls, the entire geographic unit should be restored to attain unrestricted status.

Figure 3-1. Hanford Future Site Uses Geographic Areas.



4.0 CONTAMINANT HYDROGEOLOGY

This section presents the geologic and hydrologic features that control the direction and rate of groundwater flow. The major plumes on the Hanford Site are tabulated and described relative to the quantity and extent of contaminants. Distribution patterns are also discussed. A detailed description of Hanford Site geology and hydrology is provided in DOE-RL (1993a) and Johnson (1993).

The physical, chemical, and hydraulic characteristics of stratigraphic units determine contaminant flowpaths and migration rates. These features also influence the capability to intercept and remediate a contaminant plume. Knowing these characteristics, along with a history of wastewater disposal, the basis for selecting appropriate methods to remediate groundwater and/or restrict the spread of contamination is formed.

4.1 HYDROLOGIC CHARACTERISTICS

The Hanford Site is located in the Pasco Basin, a broad sediment-filled depression that lies within the larger Columbia Basin physiographic province. The Hanford Site is noted for its thick sedimentary fill, wide areal variability in water and contaminant movement, deep unconfined aquifer, and limited natural recharge to the aquifers.

4.1.1 Vadose Zone

The soil column above the water table is dominated by unconsolidated sandy gravels (Hanford formation) that were deposited during glacial activity during the last one million years. These sediments are highly transmissive to water. The finer grained Plio-Pleistocene unit and early "Palouse" soil locally separate the underlying Ringold Formation from the Hanford formation. The downward movement of moisture is slowed wherever the Plio-Pleistocene unit and the early "Palouse" soil are present. In the eastern part of the Hanford Site, the water table is present in the Hanford formation. Evapotranspiration prevents most of the precipitation from reaching groundwater. In non-vegetated areas such as industrial areas and sand dunes, infiltration may exceed 10 cm/yr. The thickness of the vadose zone ranges from 0 m (0 ft) near the Columbia River to over 106 m (348 ft) in the south-central portion of the Hanford Site.

The stratigraphy above the water table in the Central Plateau and other areas has a profound influence on the movement of liquid effluent through the soil column beneath many waste disposal sites. Layers of fine-textured sediment slow the downward movement of water, resulting in saturated water zones above and separated from the top of the unconfined aquifer ("perched" water zones). This condition expands the source area beyond the physical dimensions of a disposal facility. It also significantly influences the time required for contaminants to reach the water table. Extended drainage periods may persist following termination of wastewater disposal operations. The interplay between stratigraphy and disposal operations is an important element in planning groundwater remediation.

4.1.2 Aquifers

The unconfined aquifer generally occurs in unconsolidated to semi-consolidated silts, sands, and gravels of the Ringold Formation. These sediments were deposited by the Columbia River as it meandered across the central Pasco Basin during the past several million years. The Ringold Formation is less transmissive to water than Hanford Site sediments. Groundwater flow rates are highly variable due to aquifer heterogeneity, but generally range from less than 0.30 m/day (1 ft/day) to several meters per day (Freshley and Graham 1988). The highest rates are in the unconsolidated gravelly sands of the Hanford formation, and similar deposits in the Ringold Formation. The aquifer ranges in saturated thickness from 0 m (0 ft) near the margins of the Pasco Basin to approximately 60 m (197 ft) near the center of the Basin (DOE-RL 1993a).

Underlying the Ringold Formation are the Columbia River Basalts, which are extensive layers of flood basalt. The basalts contain numerous confined aquifers, some of which are regional water sources. Vertical movement of water between aquifers may occur along fractures or faults in some areas (Early et al. 1988).

4.1.3 Aquifer Recharge

Both natural and artificial sources of water recharge the aquifers within the Pasco Basin. The most significant volume source is irrigation water from the Columbia Basin Project, although the influence is limited to the area north of the Columbia River, because the river acts as a groundwater flow divide for the unconfined aquifer.

Irrigation in the upper Cold Creek Valley to the west of the Hanford Site may contribute a portion of the recharge to the unconfined aquifer beneath the Central Plateau. Recharge from the Cold Creek Valley watershed has been estimated to range from 0.06 m^3/sec (2 ft^3/min) to 0.34 m^3/sec (12 ft^3/min) in studies by investigators (BHI 1996c). The volume of recharge is uncertain, because much of the irrigation water is lost to evaporation. Artificial recharge caused by Hanford Site operations historically has produced major groundwater mounds in the 200 East and 200 West Areas. The reduction or cessation of waste disposal has resulted in declines in water table elevations across much of the 200 Areas. The disappearance of mounds and changes in water table elevations have changed contaminant plume characteristics. At the southern end of the Hanford Site, the city of Richland maintains a groundwater storage "reservoir" that creates a groundwater mound, which influences groundwater flow directions in the 1100 Area.

4.1.4 River/Groundwater Interaction

The interaction between the Hanford Site aquifer and the Columbia River is an important element in assessing contaminant impacts on the river system. River water moves in and out of the banks during daily stage fluctuations, causing variable water quality characteristics in shoreline monitoring wells. Also, the interface zone between the river and the aquifer has characteristics that may retard or modify contaminants being transported by groundwater (Peterson and Johnson 1992).

4.1.5 Direction and Rate of Groundwater Movement

Contaminant plumes move in directions that are approximately perpendicular to the water table elevation contours. Plume maps that represent typical chemical and radiological waste indicators are shown in Figures 4-1 and 4-2. During the operating history, changes in the volume of liquid waste disposed to the soil column have changed the shape of the water table, resulting in alterations to migration patterns.

In the 100 Areas, the rate of flow toward the Columbia River is variable, ranging up to 4.6 m/day (15 ft/day). The rate is strongly influenced by river stage within several hundred meters of the shoreline. During extended periods of high river stage, flow is temporarily inland from the river, resulting in bank storage of Columbia River water. An upward hydraulic gradient is often present from deeper, confined aquifers, which works against downward migration of contamination.

On the Central Plateau, average rates of movement in the upper unconfined aquifer are about 0.15 m/day (0.5 ft/day) in the 200 West Area and 0.3 to 0.61 m/day (1 to 2 ft/day) elsewhere; however, locally flow rates may reach as high as 6 m/day (20 ft/day). Flow rates in the confined aquifers are much slower (<0.003 m/day [<0.01 ft/day]). The potential for downward vertical movement of groundwater from the unconfined aquifer into the upper confined system in some areas beneath the Central Plateau exists, as revealed by the decrease in hydraulic head with depth (Johnson et al. 1993, Spane and Webber 1995).

Groundwater monitoring results indicate the occurrence of contaminants in the confined aquifers including tritium, nitrate, iodine-129, technetium-99, and cobalt-60 (Dresel et al. 1994; Spane and Webber 1995; Early et al. 1988). Contaminant concentrations are generally below maximum contaminant levels (MCL) and can be attributed to the absence of upper basalt confining units, structural deformation (fracture controlled intercommunication), the presence of erosional paleostream channels (Spane and Webber 1995), and open or unsealed well pathways (Dresel et al. 1994). Principle areas of aquifer intercommunication between the upper basalt and unconfined aquifer occur north of the 200 East Area, and in areas of present or past groundwater mounding (e.g., B-Pond and Gable Mountain Pond). Contamination is moving at low lateral velocities estimated at 1.5 to 2.2 m/yr (Spane and Webber 1995), at downward flow rates between 4.5 and 6 m/yr (Early et al. 1988), and is not believed to be migrating offsite within the confined aquifer system.

Marked variations in permeability occur within the unconfined aquifer, especially in the 200 West Area. Variable cementing of the aquifer sediments accounts for most of the differential permeability in the 200 West Area. Within the 200 East Area, the major source of variability is whether the water table is located within the Ringold Formation or the more permeable Hanford formation.

The interaction of natural and artificial recharge sources with the variation in aquifer permeability across the Central Plateau controls the direction and rate of movement of contaminant plumes that originate from past-practice disposal sites within the 200 West and

200 East waste management areas. The rate of movement is also influenced by the chemical reactivity of the contaminant in the environment.

Two general flow directions are observed for the major contaminant plumes originating in the Central Plateau: (1) to the southeast with discharge to the Columbia River between the old Hanford townsite and the 300 Area, and (2) through Gable Gap with discharge to the river between the 100-B and 100-D Reactor areas (Figure 4-3). Predictions of the direction and rate of movement for each major contaminant plume are discussed in Section 5.0.

4.1.6 Contaminant/Soil Interactions

Contaminants found in aquifers generally move with the water. However, the rate of contaminant movement is often less than the rate of water movement due to fixation and adsorption reactions. Fixation will remove a contaminant from water and affix it within the structure of the mineral. Adsorption also removes a contaminant from water and accumulates it on the surface of a mineral. The affinity of a contaminant for a soil is defined by its distribution coefficient. Generally, the higher the value of the distribution coefficient, the greater is the affinity of the contaminant for soil and the slower it moves in the aquifer.

Table 4-1 presents values of the distribution coefficient considered representative of Hanford Site soils for each major contaminant. A value less than five is considered highly mobile, between 5 and 100, moderately mobile, and greater than 100, immobile. For each radionuclide, radioactivity decay half-lives are also provided in Table 4-1. A half-life is the interval of time for a radionuclide to decay to one-half of its original quantity. A contaminant with a short half-life will decrease more rapidly than one with a long half-life.

4.2 CONTAMINANT PLUME DISTRIBUTION PATTERNS AND VOLUMES

The major contaminant plume boundaries in the unconfined aquifer, as defined by exceedance of *Model Toxics Control Act* (MTCA) groundwater protection standards, DWSs, Washington State Water Quality Standards, or equivalent concentrations, are shown in Figures 4-1 and 4-2. The directions and distribution patterns reflect the interaction of hydrogeologic conditions, disposal chronologies, and contaminant chemistries. For descriptive purposes, most of these plumes have been grouped into the Central Plateau and 100 Areas reactor sites geographic regions. Three contaminants (nitrate, tritium, and iodine-129) are discussed as sitewide plumes.

Several contaminant plumes overlap because of either merging of separate plumes from different sources, or because they were released as cocontaminants. The lateral extent of plume movement is influenced by the chemical reactivity or tendency of the contaminant to adhere to aquifer sediments, especially fine-grained material. Constituents such as tritium, nitrate, and technetium-99 do not interact with aquifer solids and are therefore the most widely distributed. Chlorinated hydrocarbons are only slightly adsorbed and are thus expected to be minimally influenced by aquifer solids. Strontium-90, cesium-137, and plutonium are highly reactive and/or form insoluble solid phases in groundwater, and are thus very limited in areal extent.

The only attenuation mechanisms for nitrate, biologically mediated denitrification or biological assimilation, are assumed to be of minimal importance in Hanford Site aquifers, although in at least one study (Newcomer et al. 1995), facultative denitrifiers were predominate at a 200 West site.

4.2.1 100 and 200 Areas Plumes

Table 4-2 provides estimates for individual contaminant masses and volumes within the plume boundaries shown in Figures 4-1 and 4-2. The volume estimates assume that the sampling depths of the monitoring wells upon which the plume contours are based represent the average concentration over an assumed maximum depth of 10 m (32.8 ft). In some cases, significant concentrations have been observed to a depth of 30 m (98 ft). Depth distribution is clearly an important factor that can significantly impact remediation strategy and the likelihood of success. The lack of definition of vertical contaminant distribution in the unconfined aquifer is a major issue that must be resolved.

The quantities or masses associated with aquifer solids listed in Table 4-2 were calculated using the pore fluid quantities (columns 3 and 4) and published distribution coefficients for Hanford Site soils (Ames and Serne 1991).

The amount associated with aquifer solids can be much greater than the amount that occurs in pore fluid (e.g., strontium-90, cesium-137, and plutonium). Additionally, the total amount associated with pore fluid and aquifer solids relative to the total released is an important factor in assessing the fate of contaminants discharged to the soil column. For example, the total quantity of strontium-90, shown in Table 4-2, is less than 1% of an estimated 76-89 Ci contained in the unconfined aquifer (Serne and LeGore 1996). This suggests that a large fraction remains in the vadose zone.

4.2.2 Sitewide Contamination

Three plumes in the Central Plateau extend well beyond existing CERCLA operable unit boundaries. These plumes have concentrations that fall both above and below accepted groundwater standards. The waste constituents are tritium, iodine-129, and nitrate. Reference is made to Section 5.10 for a description of an approach to remediation. The plumes have the following elements in common:

- Widespread, covering tens of square miles
- Limited areas of high concentrations.

4.2.2.1 Tritium. This waste constituent has been introduced to groundwater at a number of locations as a result of irradiated fuel processing. Tritium was produced by ternary fission and neutron irradiation of light-element impurities such as lithium, boron, and deuterium in the fuel elements. It was estimated, before condensate recycle was instituted at the PUREX Plant, that about 90% of the tritium in the fuel elements was discharged as water to cribs and surface ponds, that about 7.5% of the tritium was discharged in the high level waste, and the remainder was discharged to the atmosphere (WHC 1989). Processing records indicate that the quantity of tritium discharged on the Hanford Site is approximately 220,000 Ci (decay corrected to December 31, 1992). Estimates for tritium based on groundwater sampling information yields a roughly comparable estimate of 210,000 Ci. The distribution of tritium on the Hanford Site is shown in Figure 4-4.

Tritium is an isotope of hydrogen. It replaces or exchanges with nonradioactive hydrogen in water molecules and thus becomes part of the water molecule. In the environment it is indistinguishable from nontritiated water and moves with the same characteristics. The only attenuation mechanism for tritium, other than dilution, is radioactive decay with a half-life of 12.3 years.

4.2.2.1.1 Tritium Discharge to the Columbia River. Data from the Pacific Northwest National Laboratory environmental reports from 1984 through 1992 have been used to estimate the Hanford Site discharge of tritium into the Columbia River. Before 1984, reported differences between upstream and downstream measurements were not statistically significant. Tritium migration into the Columbia River ranged from 3,800 to 8,400 Ci/yr during this period. The highest value occurred in 1991, with a drop to 4,600 Ci/yr in 1992. The peak in 1991 may correspond to the entry of the higher concentration portions of the Hanford townsite plume into the river. Data indicate the first arrival of significant quantities of tritium at the Columbia River near the Hanford townsite in either 1975 or 1976.

4.2.2.1.2 Extent of Tritium Contamination. An approximation of the quantity of tritium in Hanford Site groundwater, based on limited data concerning the deep occurrences of tritium, assumes that the tritium plume concentration in the Central Plateau extends to depths of 60 m (197 ft) in the 200 West Area and 20 m (66 ft) in the 200 East Area, and to depths of 20 m (66 ft) in the 600 Area, east and southeast of the 200 East Area, and in the Gable Gap. This approximation yields a total tritium groundwater inventory of 210,000 Ci. This value is approximately 5% less than the estimated quantity discharged; however, when added to the 45,000 Ci (decay corrected) estimated for river discharge, there is an indication that there is a discrepancy of approximately 15%. The estimate is in reasonable agreement with the discharge estimates, particularly in consideration of the uncertainties in both the quantity of tritium produced and in estimates of the deep distribution of tritium.

4.2.2.2 Iodine-129. Iodine-129 is a groundwater contaminant of concern because of its relatively long half-life (16 million years) and low regulatory standard (DWS = 1.0 pCi/L). The analytical detection limit for iodine-129 is about 1 pCi/L. Three extensive plumes of iodine-129 contamination originated from Central Plateau liquid waste disposal facilities that received process wastewater (Figure 4-5).

4.2.2.2.1 Iodine-129 Plume Migration. Iodine-129 occurs in wastewater and groundwater as mobile anionic species (I^- or IO^-) and generally travels at the same velocity as groundwater. Its distribution and centers of highest concentration roughly coincide with the tritium contaminant plumes that underlie the Central Plateau. There are no analytical data indicating that iodine-129 in concentrations exceeding the detection limit (1 pCi/L) have entered the Columbia River. The edge of the plume appears to be 2.5 to 3 km (1.6 to 1.9 mi) from the Columbia River in the vicinity of the Hanford townsite.

4.2.2.2.2 Extent of Iodine-129 Contamination. Iodine-129 contamination is present in the unconfined aquifer, over 75 km^2 (29 mi^2) of the central portion of the Hanford Site. Because iodine-129 is a co-contaminant with tritium in the Central Plateau and has about the same mobility as tritium (its movement may be slightly retarded relative to tritium), its distribution at depth in the aquifer should be similar. Iodine-129 may be present to depths of 60 m (197 ft) beneath the 200 West Area and 20 m (66 ft) beneath the 200 East Area and the 600 Area east and southeast of the Central Plateau.

4.2.2.3 Nitrate. Nitrate contamination is present in all operational areas, as well as in significant portions of the 600 Area. Nitric acid and aluminum nitrate were used in numerous site processes related to decontamination and fuel reprocessing activities. Acid waste solutions are the primary contributor to nitrate plumes currently observed in groundwater. The distribution of nitrate is shown in Figure 4-6.

Nitrate is an extremely mobile anion that moves at the same velocity as the groundwater. The anion is not retarded by sorption. The only attenuation mechanisms for nitrate, biologically mediated denitrification or biological assimilation, are assumed to be of minimal importance in Hanford Site aquifers, although in at least one study (Newcomer et al. 1995), facultative denitrifiers were predominate at a 200 West site.

4.2.2.3.1 Nitrate Discharge to the Columbia River. Nitrate is currently being discharged at concentrations exceeding the DWS to at least four stretches of shoreline along the 100 Areas of the Columbia River. A significant stretch of shoreline adjacent to the Hanford townsite is the locus of nitrate discharge from 200 East Area sources at concentrations slightly below the DWS. It appears that the arrival of the nitrate plume at the Hanford townsite was coincidental with the tritium plume. Both tritium and nitrate show marked increases in well 699-40-1 beginning in 1975. Nitrate concentrations exceeded the DWSs beginning in 1984 and remained elevated for 2.5 to 3 years. Concentrations in the well have remained slightly below the DWS from 1986 to the present.

4.2.2.3.2 Extent of Nitrate Contamination. The net area of nitrate contamination that exceeds the DWS for the Hanford Site as a whole is 55 km^2 (21 mi^2). As nitrate appears to have moved as a co-contaminant with tritium, it seems reasonable that a similar depth distribution profile is probable for plumes emanating from the Central Plateau as described in the tritium plume volume discussion (Section 4.2.2.1.2). With the assumption that nitrate contamination extends to depths of 60 m (197 ft) in the 200 West Area, to depths of 20 m (66 ft) in the 200 East Area and in the 600 Area east and southeast of the 200 East Area and in Gable Gap, and to 10 m (33 ft) elsewhere on the Hanford Site, the total volume of nitrate-contaminated groundwater beneath the Hanford Site is estimated to be 1.6×10^8 m^3 (4.2×10^{10} gal).

It should be noted that some nitrate contamination originates from sources west and southwest of the Hanford Site. For example, one of the larger plumes exceeding 45-mg/L is located west of the 200-West Area, and is probably associated with agricultural activities in the upper Cold Creek Valley (Figure 4-6).

4.2.2.4 Other Areas (300 and 1100 Areas). The 1100 Area groundwater is relatively uncontaminated. The only contaminant of concern that comprises a plume is trichloroethylene (TCE). The plume is dissipating as it moves slowly to the northeast with concentrations up to 58 ppb. The plume is estimated to cover an area of about 0.5 km^2 (0.2 mi^2) and contain approximately 41 kg (90 lb) of contaminant (based on a porosity of 0.25 and an assumed depth of contamination of 10 m [33 ft]).

Groundwater contamination within and near the 300 Area is described by Dresel et al. (1994). Contaminants identified in this area are uranium, TCE, 1,2 dichloroethylene (DCE), and tritium. Uranium, DCE, and TCE occur in concentrations above regulatory standards and are the result of fuel fabrication previously conducted in the area. Tritium contamination is from past process activities found in the 200 Areas and has not been detected in the 300 Area at levels above DWS (DOE-RL 1995c).

Nitrate concentrations above the 45-mg/L MCL are found upgradient (west) of the 1100 area and both upgradient and downgradient of the Siemens Power Corporation facility (Siemens Power Corporation 1996). Fertilizer and irrigation applied to upgradient agricultural fields, as well as industrial activity at the Siemens facility are likely sources of nitrate (PNNL 1996).

Figure 4-1. Areal Distribution of Chemical Contaminants.

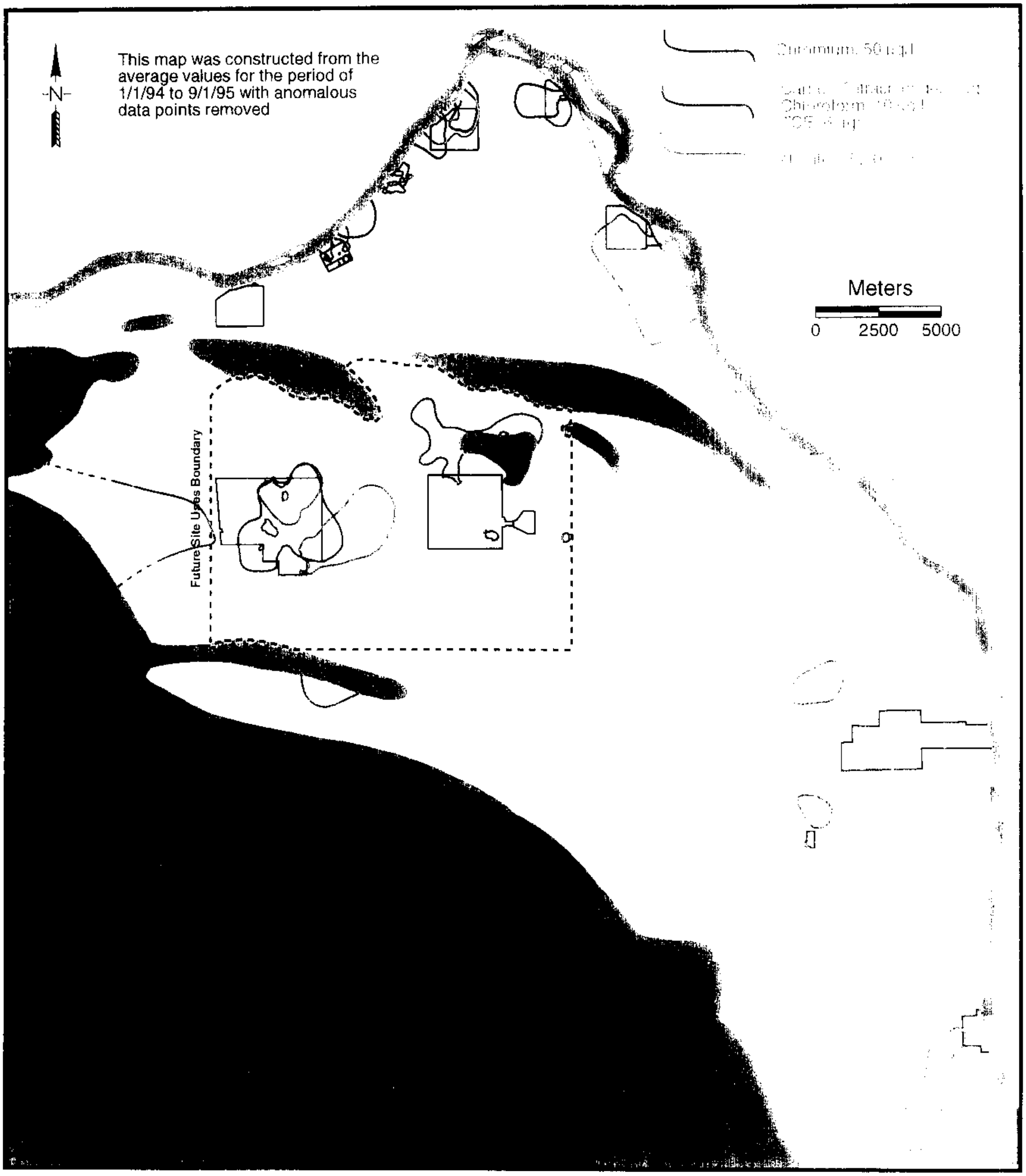


Figure 4-2. Areal Distribution of Radioactive Contaminants.

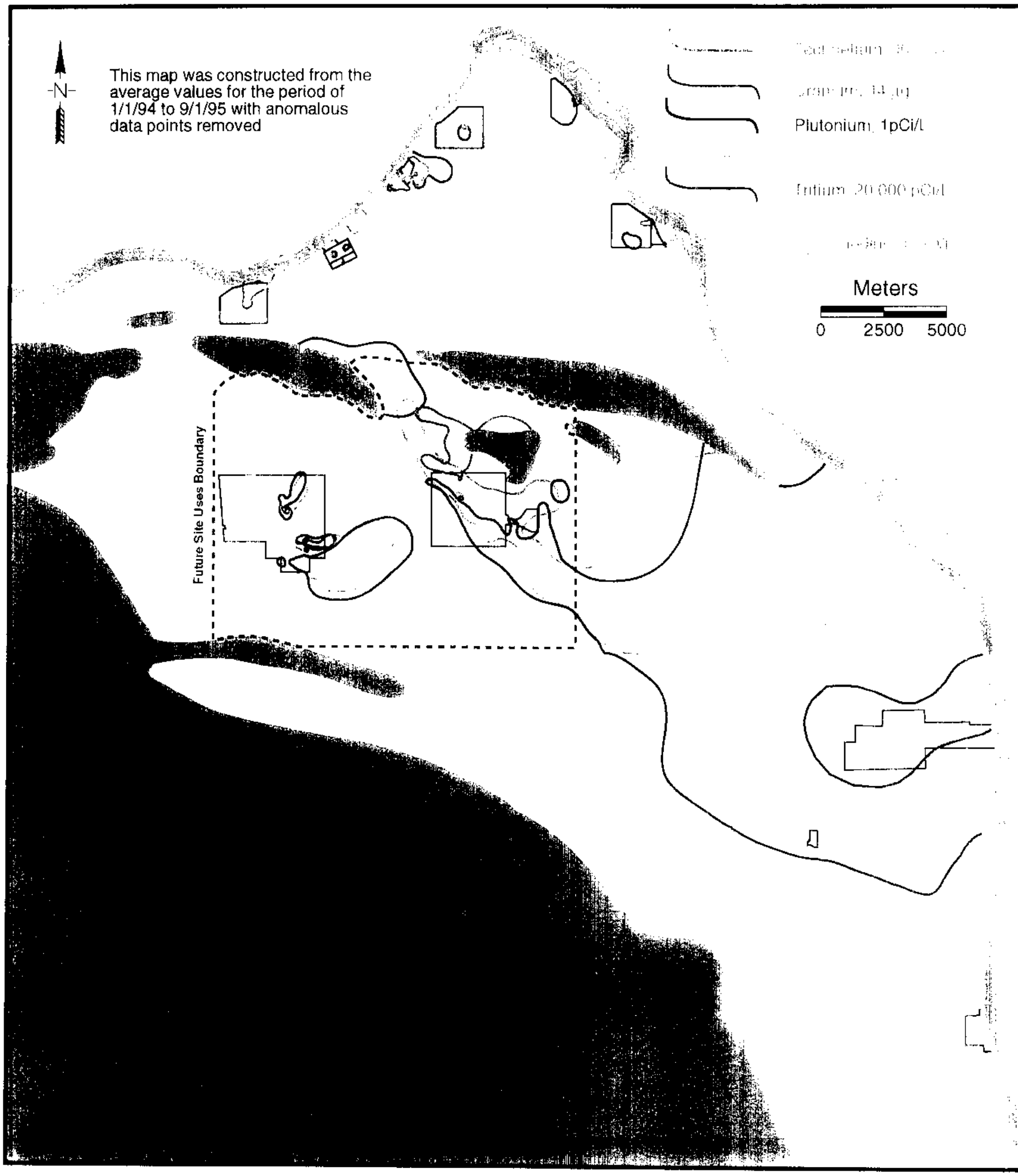


Figure 4-3. Groundwater Streamlines for the Central Plateau.

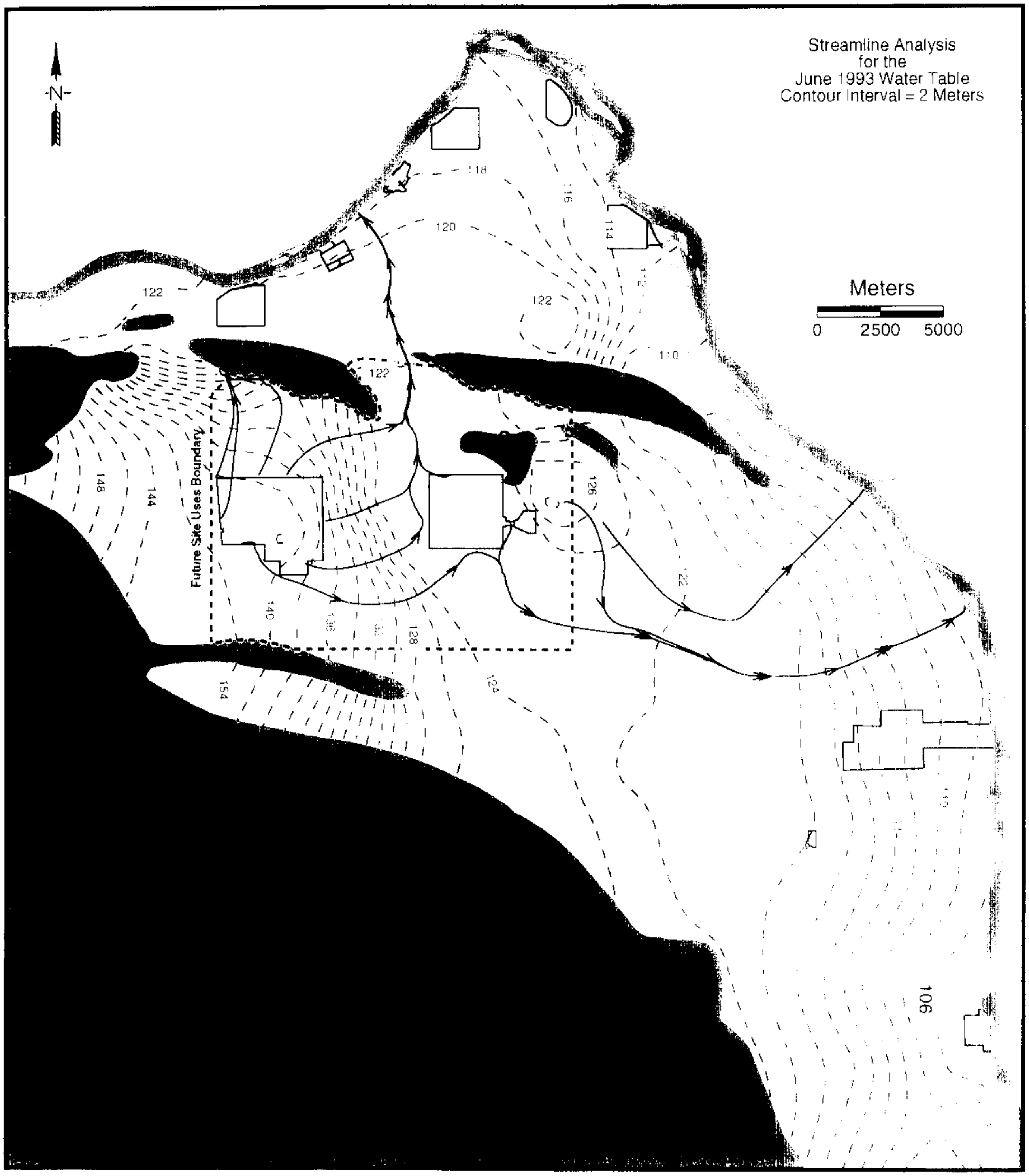


Figure 4-4. Map of the Hanford Site Showing Areal Extent of Major Tritium Plumes.

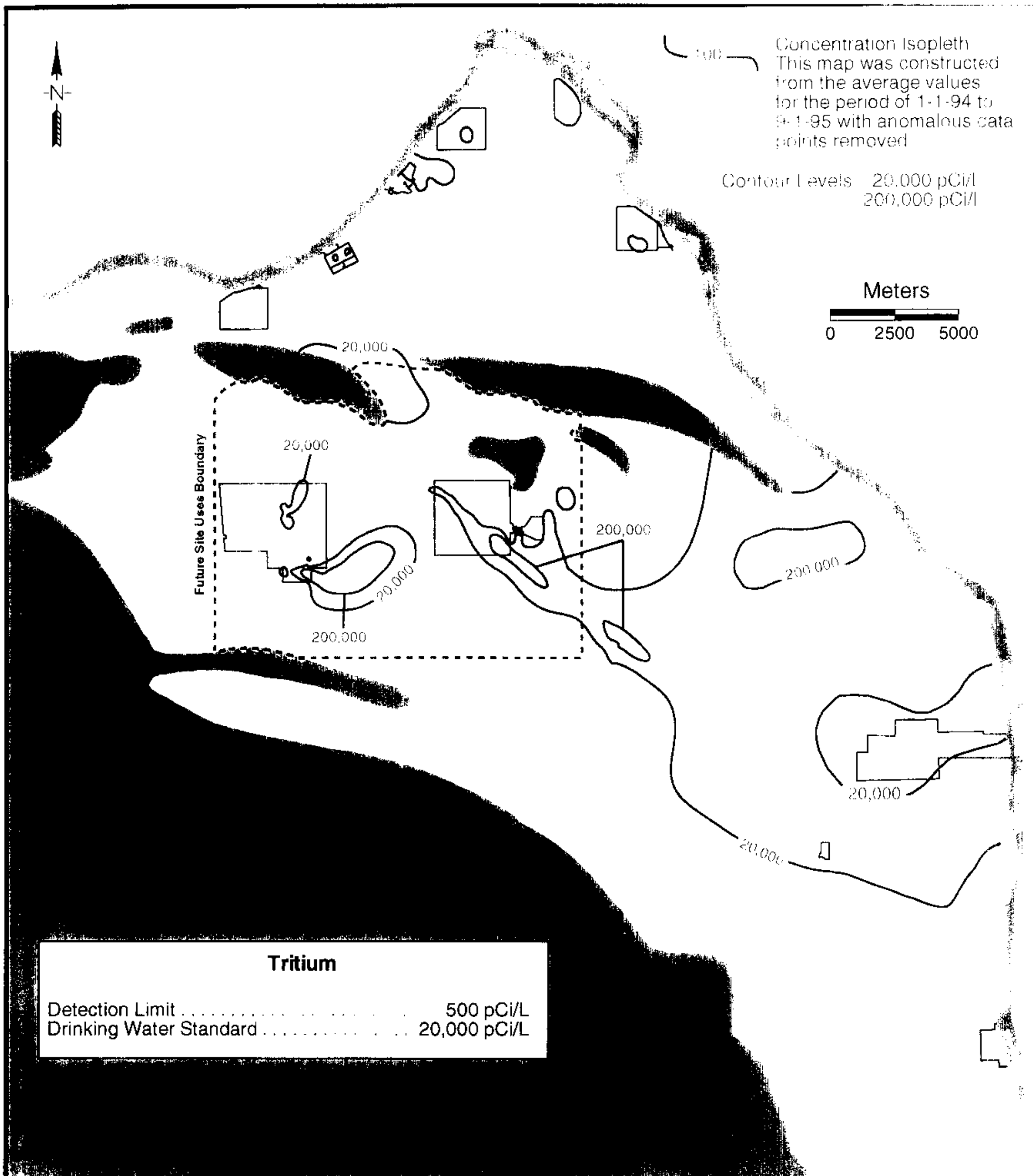


Figure 4-5. Hanford Site Map Showing Areal Distribution of Iodine-129 Plumes.

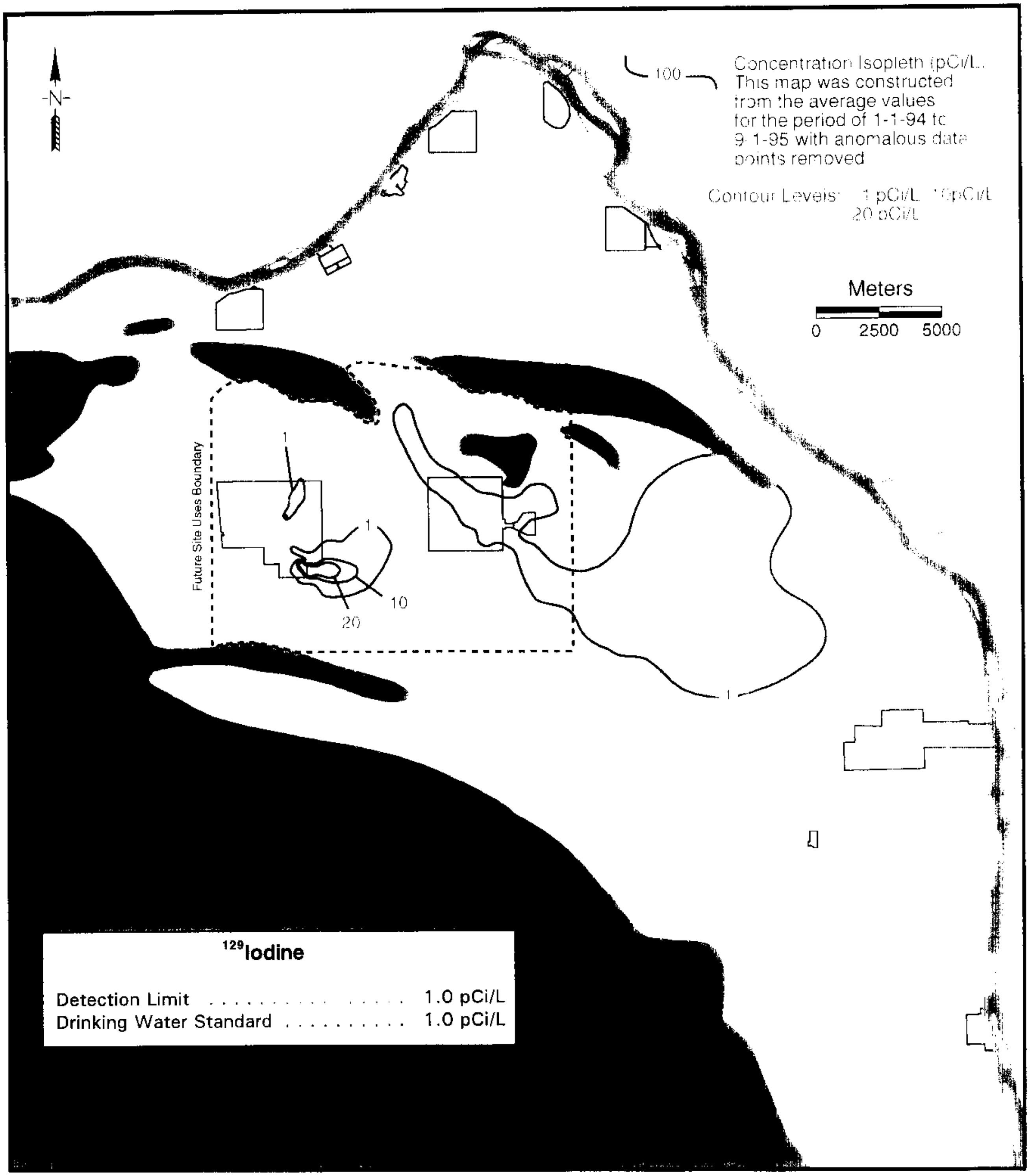


Figure 4-6. Hanford Site Map Showing Areal Distribution of Nitrate Plumes.

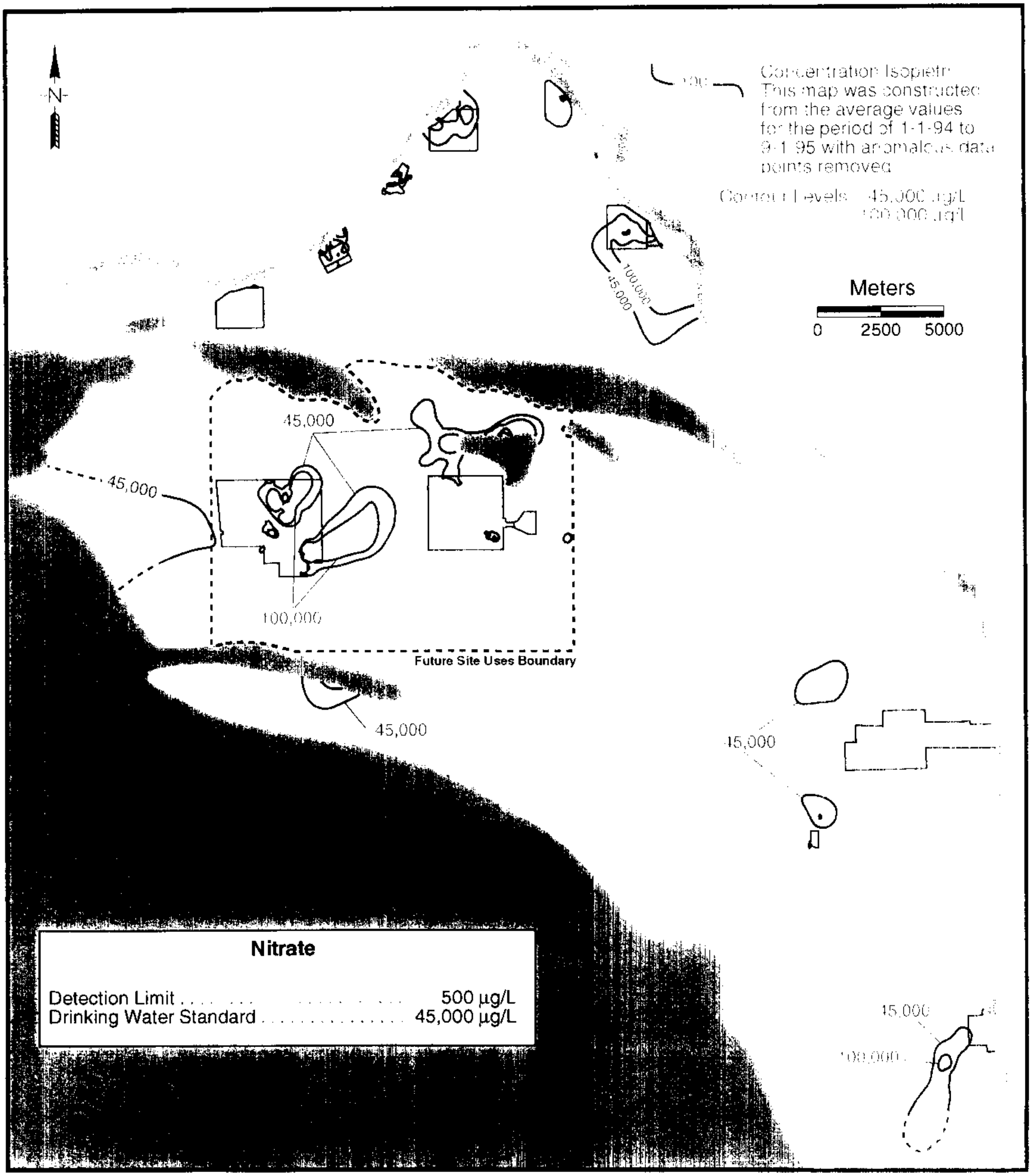


Table 4-1. Soil Distribution Coefficients and Radioactivity Decay Half-Lives.[a]

Contaminant	Representative Distribution Coefficient (mL/g)	Half-Life (years)
Uranium-234/235/238	0-0.5	2.47E5, 7.1E8, and 4.51E9
Technetium-99	0	2.12E5
Carbon tetrachloride	0-0.2	N/A
Plutonium-239/240	200	2.4E4
Cesium-137	50	30.2
Cobalt-60	50	5.25
Strontium-90	25	28.9
Chromium VI	0	N/A
Tritium	0	12.3
Iodine-129	0-1	1.7 E7
Nitrate	0	N/A

N/A = not applicable.

[a] Modified from Ames, L. L. and R. J. Serne, 1991, *Compilation of Data to Estimate Ground Water Migration Potential for Constituents in Active Liquid Discharges at the Hanford Site,* PNNL 7660, Pacific Northwest National Laboratory, Richland, Washington.

Table 4-2. Contaminant Plume Dimensions and Volumes. (Page 1 of 2)

Project	Target Contaminants	Quantity				Extent of Contamination		
		In Pore Fluid		On Aquifer Solids		Area		Pore Fluid Volume
		(Ci)	(g)	(Ci)	(g)	(m^2)	(mi^2)	(L)
200 West Area								
200-UP-1[a]	Uranium	N/A	1.4E+5	N/A	2.5E+11	5.7E+5	2.2E-1	5.7E+8
	Technetium-99	1.5	9.7E+1	0	0	4.4E+5	1.7E-1	4.2E+8
200-ZP-1[a]	Carbon tetrachloride	N/A	5.3E+6	N/A	-[d]	1.0E+7	3.9	1.1E+10
	Chloroform	N/A	4.3E+4	N/A	-[d]	2.0E+6	7.7E-1	2.0E+9
	Trichloroethylene	N/A	9.7E+3	N/A	-[d]	8.3E+5	3.2E-1	8.3E+8
200 East Area								
B-5 Reverse Well[a]	Plutonium-239	1.0E-1	1.6	2.4E+2	4.3E+3	3.1E+2	1.2E-4	7.8E+5
	Cesium-137	8.1E-4	9.3E-6	2.4E-1	9.3E-6	3.1E+2	1.2E-4	7.8E+5
	Strontium-90	4.1E-2	2.9E-4	6.2	4.4E-2	6.6E+4	2.5E-2	1.7E+8
	Technetium-99	18.0	1.0E+3	0	0	2.7E+6	1.0	6.7E+9
	Cobalt-60	3.7E-2	3.3E-5	0	0	9.3E+4	3.6E-2	2.3E+8
Reactor Areas								
100-K Area[b]	Chromium	N/A	2.5E+5	N/A	0	1.3E+6	5.0E-1	1.7E+9
	Strontium-90	2.1E-2	1.5E-4	3.2	2.3E-2	4.0E+5	1.5E-1	5.1E+8
100-D Area[b]	Chromium	N/A	5.9E+5	N/A	0	2.6E+6	1.0	2.9E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7

Table 4-2. Contaminant Plume Dimensions and Volumes. (Page 2 of 2)

Project	Target Contaminants	Quantity				Extent of Contamination		
		In Pore Fluid		On Aquifer Solids		Area		Pore Fluid Volume
		(Ci)	(g)	(Ci)	(g)	(m^2)	(mi^2)	(L)
100-H Area[b]	Chromium	N/A	2.5E+5	N/A	0	2.1E+6	8.1E-1	2.6E+9
	Strontium-90	6.6E-4	4.7E-6	9.9E-2	7.0E-4	1.8E+4	6.9E-3	2.2E+7
100-F Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	7.5E-3	5.3E-5	1.1	7.9E-3	7.5E+4	2.9E-2	9.4E+7
100-N Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	8.8E-2	7.4E-3	1.3E+1	1.1E+0	8.2E+5	3.1E-1	6.5E+8
100-B/C Area[b]	Chromium	N/A	0	N/A	0	0	0	0
	Strontium-90	2.6E-2	1.9E-4	3.9E+0	2.8E-2	7.6E+5	2.9E-1	9.5E+8
Sitewide								
Sitewide[c]	Tritium	2.5E+4	1.8E+1	0	0	1.9E+8	7.3E+1	5.3E+11
	Iodine-129	1.2E+0	8.4E+3	0	0	7.5E+7	2.9E+1	3.7E+11
	Nitrate	N/A	4.1E+10	N/A	0	5.5E+7	2.1E+1	1.6E+11
Other Areas								
1100	Trichloroethylene	N/A	41.4 E+3	N/A	-[d]	4.8 E+5	2.0 E-1	1.2 E+9
300[b]	Uranium (DOE-RL 1995c)	.04	6.1E+4	0.47	6.7E+5	5.6E+5	2.2E-1	0.8E+9

[a]Assumes that plumes have an average thickness of 10 m (32 ft).
[b]Assumes that plumes have an average thickness of 5 m (16 ft).
[c]Assumes plume thickness as described in Section 4.2.2.
[d]No estimates available.

5.0 SITEWIDE GROUNDWATER REMEDIATION STRATEGY

The goal of groundwater remediation is to restore groundwater to its intended beneficial uses in terms of protecting human health and the environment and to protect the Columbia River. This strategy provides a common, sitewide perspective to guide the development of remediation activities for individual operable units. Guiding principles for a comprehensive groundwater remediation approach are summarized below. These principles are developed within the context of existing groundwater conditions, the institutional and regulatory framework for remediation, and stakeholder values described in previous sections of the document. Details of specific strategy elements are addressed in the following sections.

5.1 GUIDANCE

This strategy is a geographic and plume-specific approach to groundwater remediation. It is oriented to reflect public and tribal values and priorities. The following are key elements of this strategy:

- Place a high priority on actions that protect the Columbia River and near-shore environment from degradation caused by the inflow of contaminated groundwater
- Reduce the contamination entering the groundwater from existing sources
- Control the migration of plumes that threaten or continue to further degrade groundwater quality beyond the boundaries of the Central Plateau.

5.1.1 Initial Remediation Efforts

Groundwater remediation efforts are already underway on the Hanford Site. These initial efforts will ensure the following:

- Maintain a bias toward field remediation activities by employing the HPPS (DOE-RL 1991) to accelerate interim remedial actions
- Continue implementation of accelerated groundwater remediation projects to control plume expansion, reduce contaminant mass, and better characterize aquifer response to RAs
- Identify and control sources of contaminants in the vadose zone that impede efforts to remediate groundwater.

5.1.2 Final Remediation Efforts

Succeeding phases of RAs are oriented toward implementing the final RODs, which in turn will satisfy broader cleanup objectives, such as the following:

- Achieve ARARs with respect to the value of current and potential future beneficial uses for the groundwater resource

- Develop alternative containment and remediation strategies if currently available groundwater restoration technologies prove inadequate or impracticable

- Restore groundwater adjacent to the Columbia River for unrestricted beneficial use

- Prevent further degradation of groundwater quality beyond the boundaries of the Central Plateau and ultimately restore unrestricted beneficial use of groundwater beyond that boundary.

5.1.3 Resource Optimization

An important element in the groundwater remediation strategy is optimizing the use of available resources. The following are key considerations:

- Balance the sequencing and scale of RAs to achieve efficient use of technical and monetary resources

- Incorporate existing and/or proposed treatment and disposal infrastructure

- Implement currently available technology and foster demonstrations of developing technology, where appropriate, for meeting remediation objectives

- Improve the integration of the existing groundwater monitoring networks and sampling schedules to better characterize the contamination problem and to measure the effectiveness of remediation efforts.

5.1.4 Stewardship

The stewardship responsibility for remediating and protecting groundwater resources beneath the Hanford Site will be met by the following:

- Maintaining consistency with the Hanford Site GPMP (DOE-RL 1993a)

- Coordinating RAs, whenever feasible, at CERCLA operable units with adjacent operable units, with RCRA facilities undergoing closure, and with state-permitted waste discharge facilities

- Coordinating RAs that require disposal of treated groundwater with ongoing waste management and liquid effluent programs.

5.2 GEOGRAPHIC AND PLUME-SPECIFIC APPROACH

Previous studies of Hanford Site groundwater have screened and "targeted" the major groundwater contamination plumes by geographic area. Contaminant species that are widespread and/or present serious environmental concerns are addressed in the following sections. By implementing Section 5.1 and stakeholder values (see Section 3.0), an initial cleanup approach of containment and mass reduction is assigned to the major contaminant plumes identified in the Central Plateau, where necessary and feasible. Similarly, contaminant plumes found in the reactor areas are assigned an initial cleanup approach of remediation, which may also constitute final action for these plumes if data show that interim remedial actions are effective. Table 5-1 lists the major contaminant plumes and their cleanup approach. These site-specific approaches are based on an initial evaluation of available data. Relevant technical information collected to date on the Hanford groundwater contaminant plumes is compiled in *Hanford Sitewide Groundwater Remediation Strategy - Supporting Technical Information* (BHI 1996a). More detailed evaluations will subsequently be conducted in accordance with CERCLA or other appropriate regulatory requirements.

The cleanup approaches reflect the public values of protecting the Columbia River, controlling the spread of contamination, and eliminating recontamination of cleaned areas of groundwater. The assigned approach is intended to guide the initial approach to cleanup and is not intended to limit additional cleanup, should it prove feasible.

The groundwater remediation strategy also selects plumes in the reactor areas and the Central Plateau as having higher priority over others in their respective areas. The strontium-90 plume located at N Reactor and the chromium plumes in the 100-D, 100-H, and 100-K Areas are selected in the reactor areas. The carbon tetrachloride (CCl_4) plume is selected in the Central Plateau. Strontium-90 and CCl_4 are both found at levels well over regulatory standards. Strontium-90 is discharging directly to the Columbia River and is the highest source of waterborne radioactivity accessible to the public. Chromium is discharging directly to the Columbia River and has been found in concentrations in river substrates that may adversely impact aquatic life. Carbon tetrachloride is a suspected human carcinogen and is the largest of the targeted plumes; it has the potential to contaminate still larger areas. Beyond these plumes, prioritization is given to contamination of limited areal extent found anywhere on the site where immediate action would prove beneficial.

For each area and plume, an overview of hydrochemical conditions is provided, followed by a summary of contaminant transport predictions and a brief description of an approach to cleanup. Major data and information gaps are identified along with areas where technology development could potentially accelerate groundwater cleanup or be more cost effective.

Three widespread contaminant plumes and their remediation potential are also discussed: radioactive iodine-129, tritium, and nitrate. Each covers large areas, is often found above groundwater standards, and poses significant challenges to remediation. These plumes have not been "targeted" for immediate action.

Contaminants such as fluoride and arsenic that are detected as small, localized plumes or "hot spots" are best addressed on the more detailed level of the operable unit. Section 5.11 discusses important issues surrounding the disposal of treated and partially treated groundwater.

5.3 CENTRAL PLATEAU, 200 WEST AREA--URANIUM AND TECHNETIUM-99 CONTAMINATION

5.3.1 Hydrochemical Conceptualization

Uranium and technetium-99 plumes associated with the 216-U-1/2 Cribs are expected to continue moving eastward from the 200 West Area. The rate of contaminant movement will decrease as the water table declines in the 200 West Area and the hydraulic gradient is subsequently reduced. Remediation of both plumes is complicated by the textural variability and permeability of the geologic formation containing the plume, by the interaction of dissolved uranium with aquifer sediments, and by the presence of cocontaminants.

5.3.2 Contaminant Transport Predictions

Assuming no soil interaction (distribution coefficient $K_d = 0$), uranium peak concentration would decline to below 200 ppb within 50 years as the plume moves eastward and spreads beneath the 200 East Area and moves towards the plateau boundary (BHI 1996b). However, if a small soil interaction is assumed ($K_d = 0.5$ mL/g), uranium does not move very far from its present location. The level of soil interaction for uranium remains an uncertainty and additional data are needed. The current remediation activities that focus on containment and mass reduction of the highest concentration area of the plume will reduce peak concentrations but will not limit the plume's areal spread.

Technetium-99 would not move much beyond the 200 West Area and is predicted to drop below 900 pCi/L (calculated MCL based on a 4 mrem/year DWS) in 50 years through natural attenuation without remedial action. Although a remediation scenario was not simulated, it is expected that the current remediation activities will accelerate the reduction of technetium-99 concentrations.

5.3.3 Initial Remediation Approach

Remediation of the uranium and technetium-99 plumes requires a combination of source identification and possible control, plume containment, and treatability testing. Although the transport of the highest concentrations of uranium contamination may be reduced by hydraulic controls, the final level of cleanup that can be accomplished through active pump-and-treat remediation is likely to be above current ARARs using existing technologies. Technetium-99 is expected to be more amenable to pump-and-treat methods than uranium, and active remediation is expected to accelerate the attenuation of technetium-99.

A multiple-phase approach is being conducted that addresses data needed for design, containment, and/or remediation. Phase I includes the following:

- Determining the vertical extent of contamination
- Identifying continuing sources of contamination that would affect the permanence of cleanup efforts
- Treatability testing to evaluate alternatives for removing and treating groundwater
- Conducting studies to better define the direction and rate of movement.

Based on the results of Phase I, Phase II implements the selected alternative. Containing the spread of the contamination is the initial goal while information is collected and analyzed before the implementation of a larger remediation system, if warranted. Existing site treatment infrastructure (e.g., the 200 Areas ETF) is being considered during the selection of treatment alternatives.

5.3.4 Technology Development

Technology development directed at restricting the movement of uranium in the unsaturated and saturated zones is of particular interest, which might include, for example, improved grouts and other flow-restricting additives, chemical agents directed at altering the mobility of the contaminants, and improved application methods. Current technology used for uranium and technetium removal from groundwater is ion exchange. Improved and more cost-effective physical-chemical groundwater treatment technologies for uranium and technetium-99 are also potential areas for technology development.

5.4 CENTRAL PLATEAU, 200 WEST AREA, ORGANIC CONTAMINATION

5.4.1 Hydrochemical Conceptualization

A CCl_4 plume in the 200 West Area is moving eastward from the vicinity of cribs associated with the Plutonium Finishing Plant. The rate of plume migration will diminish as a result of declining hydraulic gradient in the 200 West Area; however, movement to the east and eventually northward through Gable Gap will likely continue.

The fate of approximately two-thirds of the total quantity of the CCl_4 discharged to the soils is unknown (Last and Rohay 1993). If present in sufficient quantities, CCl_4 can sink vertically and maintain a separate liquid phase within the vadose zone or within the aquifer. The separate liquid phase can act as a continuing source of groundwater contamination.

5.4.2 Contaminant Transport Predictions

Carbon tetrachloride is predicted to spread and cover the entire Central Plateau in time (BHI 1996b) and will migrate off the Central Plateau in about 100 years if no soil interaction is assumed. The current IRM will reduce concentrations at the heart of the plume but will be unable to stop the spread of the carbon tetrachloride plume. The carbon tetrachloride that is currently outside the IRM area accounts for the plume's spread over the Central Plateau. If a small interaction of carbon tetrachloride with the soils is assumed ($K_d = 0.114$ mL/g), the rate of spread of the plume is significantly reduced, i.e., the plume will not migrate off the Central Plateau within a 200-year period. Field and laboratory work to define the extent of carbon tetrachloride soil/groundwater interaction and the potential for biological degradation is needed to reduce uncertainties in the predictions.

5.4.3 Initial Remediation Approach

A phased approach is being pursued to address the major data gaps and to achieve containment and mass reduction of the more contaminated and known source areas. Phase I, which has been essentially completed, concentrates on defining the existence of and the ability to remediate the potential source areas and on performing pilot-scale treatability tests. Examination of the extent of contamination in the upper confined aquifer in selected locations is recommended along with remediation of unsealed wells in the area. Based on the results of Phase I, a Phase II pump-and-treat system to reduce concentrations in the most contaminated areas is being operated for the purpose of containment and mass reduction in the unconfined and upper confined aquifer.

For purposes of discussion, a preliminary remedial design and cost estimate for intercepting the entire CCl_4 plume (defined by the 5 μg/L isopleth) in the 200 West Area is attached as Appendix A. The pump and treat technology was chosen to demonstrate the general magnitude of the remediation effort that would be required to contain the CCl_4 plume within the HFSUWG boundary. If a remediation concept of this type is initiated, other technologies should be evaluated to achieve optimal performance and cost.

One of the primary objectives at DOE facilities is to reduce the long-term mortgage to the taxpayer. The modeling reported in BHI-00469, *Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions*, Rev. 1 indicates that if large scale action is not taken, the CCl_4 plume will travel beyond the boundaries of the HFSUWG boundary within the next 200 years. The effort to monitor the movement of the plume over 200 years could prove to be very expensive. Controlling the movement of the plume and reducing mass in the near-term through groundwater remediation could actually prove to be less expensive in the long-term (i.e., reduce the long term mortgage to the taxpayer). For purposes of discussion, a preliminary estimate of the monitoring costs for the 200 Area is attached as Appendix B.

5.4.4 Technology Development

Concurrent with the Phases I and II efforts, additional research is needed on improved treatment systems, containment of large plumes, in situ treatment, and immobilization methods (e.g., bio-remediation, reduction by metallic iron, enhanced natural degradation, enhanced methods to identify and remediate dense nonaqueous phase liquids).

5.5 CENTRAL PLATEAU, 200 EAST AREA, TECHNETIUM-99, COBALT-60, CYANIDE, AND NITRATE CONTAMINATION

5.5.1 Hydrochemical Conceptualization

Estimated quantities of the primary contaminants in the liquid effluent disposed to the BY Cribs include 0.45 Ci of cobalt-60; 18,900 kg (41,670 lb) of ferrocyanide; 5,700,000 kg (12,600,000 lb) of nitrate; and an unknown quantity of technetium-99 (DOE-RL 1993b, 1993c). These liquid effluents were dense brines and may have sunk into the aquifer, providing a source of continuing contamination (Kasza 1993). Plumes of technetium-99, cobalt-60, cyanide, and nitrate occur north of the 200 East Area and are believed to be associated with the BY Cribs. The plumes are moving northward through Gable Gap, and the highest concentrations occur in the vicinity of well 699-50-53A. Technetium-99 and cobalt-60 are the primary contaminants of concern at this location.

5.5.2 Contaminant Transport Predictions

Contaminant transport modeling (BHI 1996b) indicates that the technetium-99 plume will naturally dissipate through dispersion to below the MCL within about 10 years. Cobalt-60 will dissipate within about the same time frame to below MCL due primarily to radioactive decay. These results contrast to previous analytical modeling (DOE-RL 1996a) that indicated that the technetium-99 plume would migrate off the plateau at greater than MCL concentrations. However, the analytical modeling did not take the declining water levels into account. The sitewide numerical modeling (BHI 1996b) more accurately assessed the effects of flow system changes (declining water levels) and is therefore believed to be more representative.

5.5.3 Initial Remediation Approach

A phased approach consisting of the following major elements has been implemented:

- Treatability testing using a pilot treatment system to remove technetium-99 and cobalt-60 from groundwater
- Areal and vertical definition of the plume
- Confirmation of the source of contamination and what potential control measures may be needed, if any

- Implementation of hydraulic controls, if warranted, to contain the plume, reduce the mass of contaminants, and slow its spread.

The key elements of the first phase include treatability testing and the collection of improved geohydrologic information. Based on the results of Phase I, it has been concluded that interim actions to achieve source control and containment of the plumes are not warranted in view of the contaminant predictions that show that the plumes will naturally dissipate within a relatively short period of time (<10 years). Further, the treatability testing showed that because of the unique hydrogeologic conditions in this area, remediation of the plume using current pump-and-treat technology would not be practical (DOE-RL 1996a).

5.5.4 Technology Development

Existing pump-and-treat technology does not appear to be adequate to successfully remediate the BY Cribs plume, because of the unique hydrogeologic conditions in this area. Improvements in the ability to remotely determine the elevation of the bottom of the aquifer by geophysical means could prove beneficial for locating any remnants of the dense contaminant mass and for defining any preferential groundwater flow paths.

5.6 CENTRAL PLATEAU, 200 EAST AREA, PLUTONIUM, STRONTIUM-90, AND CESIUM-137

5.6.1 Hydrochemical Conceptualization

Significant quantities of plutonium, strontium-90, and cesium-137 are present in the vadose zone and aquifer material around the 216-B-5 reverse well (injection well) in the 200 East Area (Brown and Rupert 1950, Smith 1980). Strontium-90 is also a contaminant of concern in the 216-A-25 Gable Mountain Pond plume (DOE-RL 1996a). Because of high sorption coefficients and inclusion in relatively insoluble solid phases, the contaminants in the 216-B-5 reverse well plume do not represent a threat to groundwater outside of the 200 East Area. However, because of their high concentrations and long half-lives, the radionuclides, particularly plutonium, represent the potential for long-term contamination of groundwater within the 200 East Area. The Gable Mountain Pond plume, which is farther north but has not yet migrated through Gable Gap, is less of a concern because the strontium-90 is expected to decay to acceptable levels before the plume migrates a significant distance.

5.6.2 Contaminant Transport Predictions

Because these are small localized plumes, they were not included in the sitewide modeling effort. However, previous analytical modeling (DOE-RL 1996a) indicated that the cesium-137 and strontium-90 would decay to negligible levels long before the plumes migrated off the plateau and the plutonium is essentially immobile. Similar modeling of the strontium-90 in the Gable Mountain Pond plume showed that the strontium-90 would decay to acceptable levels as it migrates within about a mile from the plume's current position.

5.6.3 Initial Remediation Approach

Geochemical considerations make implementation of a pump-and-treat system at this location appear to have little chance to succeed, especially for plutonium. Further, because of the relative immobility of the contaminants of concern in this plume, an interim remedial action is not justified. Potential future actions could benefit from use of the 216-B-5 reverse well plumes as a technology development test site for the purpose of permanently controlling contamination.

5.6.4 Technology Development

Potential technology development opportunities include the following information needed to remediate contamination found at the 216-B-5 reverse well:

- Determination of what geochemical phases are controlling distribution and transport of plutonium and strontium-90
- Bench-scale tests with samples of contaminated sediments
- Development of methods for physical removal of the contaminated sediments
- Development of barrier technology to contain the contamination.

5.7 REACTOR AREAS (100 AREAS)

5.7.1 Hydrochemical Conceptualization

Groundwater contaminants in the 100 Areas are important because of their proximity to the Columbia River. Groundwater flow is generally toward the river. Principal contaminants forming plumes in the 100 Areas are strontium-90, tritium, nitrate, and chromium. The most significant of these are strontium-90, particularly in the 100-N Area, and chromium, which is toxic to aquatic organisms.

5.7.2 Contaminant Transport Predictions

Radioactive decay plots (BHI 1996b) show that the strontium-90 plume in the 100-N Area would attenuate primarily through radioactive decay to reach the MCL in about 280 years. The predictions also indicate that while pump-and-treat remediation would be effective in reducing the flux of strontium-90 to the river, it would not be effective in reducing concentrations or mass removal because the strontium-90 is highly adsorbed to the aquifer sediments.

Contaminant trend plots for chromium (BHI 1996b) indicate that chromium in the reactor areas would be expected to dissipate naturally in 10 to 50 years, although there are many uncertainties in this prediction. There is indication that continued rewetting cycles of the previously contaminated soil column above the water table may act as a continuing "source" of chromium.

There is also indication that transport of chromium from the soil to the groundwater phases may be the result of a slow diffusion process. If so, pump-and-treat remediation, while effective in reducing the flux of chromium to the river, would not be effective in reducing concentrations or achieving significant mass removal.

5.7.3 Initial Remediation Approach

The contaminants considered in the following discussion are limited to those having significant areal extent and are found at levels well above DWSs; i.e., problem areas where major efforts will be extended for remediation and that should be viewed in a sitewide context. Contaminants meeting the above general criteria for the 100 Areas include the radionuclide strontium-90, found in the 100-N Area, and the chemical contaminant chromium, found in the 100-D, 100-H, and 100-K Areas (Hartman and Peterson 1992). Strontium-90 is found at levels over 100 times the DWS of 8 pCi/L; chromium is found at levels over 10 times the freshwater fish chronic toxicity criteria of 11 ppb. Both plume types are found in groundwater discharging to the Columbia River (Peterson and Johnson 1992). Strontium-90, in sufficient concentrations, represents a potential human health hazard, and chromium is of concern due to its aquatic toxicity.

On September 23, 1994, EPA and Ecology issued an Action Memorandum to DOE-RL establishing the approach for the remediation of N-Springs. The memo included the construction of a barrier to flow of a minimum of 914 m (3,000 ft) in length between the source of contamination and the Columbia River. Additionally, a small-scale treatability test was specified to evaluate the ability of a pump-and-treat system to remove dissolved strontium-90 from the groundwater. The purpose of the barrier is to reduce the flux of dissolved strontium-90 to the Columbia River by increasing the travel time of the strontium to allow radioactive decay to mitigate the problem. Attempts to install an effective barrier using sheet piles were unsuccessful because of soil conditions. As an alternative, a pump-and-treat system was installed to provide hydraulic control of contaminant flux to the river.

The commitments made under the Tri-Party Agreement for 100-D and 100-H Reactor areas (100-HR-3 Operable Unit) include the testing of an approximately 189-L/min (50-gal/min) pump-and-treat system to remove chromium. This treatability testing has been conducted in the 100-D Area near a known source of chromium.

For each of the three chromium plumes located in the 100-D, 100-H, and 100-K Reactor areas, the remediation strategy establishes the goal of remediation for the aquifer. The proposed cleanup approach is currently pump and treat. However, while pump and treat should be effective in hydraulically controlling the chromium flux to the river, it may not be effective in achieving full remediation (i.e., reducing chromium concentrations in the aquifer), although this is subject to substantial uncertainty. It is recommended that sources of continuing contamination be identified and, if feasible and cost effective, be remediated in each area.

For most of the 100 Areas, it is recommended to continue characterization of groundwater contamination under the HPPS to fill data gaps where there are significant uncertainties that, if resolved, would lead to more cost-effective approaches to remediation. This includes monitoring during remediation of surface sources (e.g., cribs, underground tanks, and burial grounds). The need for groundwater remediation at the operable unit level should be reevaluated if undesirable changes occurred during source remedial activities, or if previously undetected contaminant problems are revealed by continued characterization efforts.

5.7.4 Technology Development

The following processes offer areas where technology improvements may improve the technical and cost effectiveness of groundwater cleanup: geochemical fixation of chromium in source areas, passive removal technologies (such as funnel and gate), improved barrier construction technologies, improved leaching/fixative methods for strontium removal/fixation, and improved physical-chemical treatment.

5.8 300 AREA

The CERCLA 300-FF-5 Groundwater Operable Unit in the 300 Area completed the RI and the FS phases and issued the proposed plan for the operable unit. The ROD was signed in July 1996.

Groundwater contamination in the 300 Area occurs in three primary areas. The principal plume is uranium contamination derived from past operations and disposal practices within the 300 Area. The uranium plume intersects the Columbia River. Tritium is encroaching from the north (originating from the Separations Area), and a plume composed of nitrates and technetium-99 is found to the south and east of the 300 Areas that is migrating toward the Columbia River. In addition to these primary plumes, small localized plumes of DCE and TCE are present that are not expected to migrate into the river at concentrations which would exceed either the MCL or surface water quality standards.

The proposed plan for the 300-FF-5 Operable Unit (DOE-RL 1995d) identifies institutional controls as the preferred alternative. Institutional controls consist of monitoring groundwater and near-shore river water in addition to placing restrictions on groundwater withdrawal and use. It is estimated that the natural attenuation would continue to decrease contaminant concentrations to levels below remedial goals in a relatively short time period. Monitoring will continue until remedial goals are met.

5.9 1100 AREA

The 1100 Area is located north of the city of Richland in the southernmost portion of the Hanford Site. Investigations leading to a ROD indicated that groundwater plumes containing TCE and nitrate, located in the vicinity of the Horn Rapids Landfill, have groundwater concentrations above standards.

The ROD requires continued institutional controls and monitoring of the groundwater to ensure that contaminant levels decrease as predicted. Modeling shows that through this remedy, TCE will attenuate naturally to below the MCL in about 20 years. In the meantime, access to the groundwater, including the drilling of wells, will be restricted. Because the groundwater is not used as a drinking water source, there are no current potential risks to human health. If monitoring does not confirm the predicted decrease of contaminant levels, the need for more intrusive remediation will be considered by the Tri-Party Agreement agencies.

5.10 SITEWIDE PLUMES--TRITIUM, IODINE-129, AND NITRATE

Three waste constituent plumes are characterized as sitewide contamination issues: tritium, iodine-129, and nitrate (Section 4.2.2).

5.10.1 Hydrochemical Conceptualization

Tritium is the most widely distributed radionuclide contaminant on the Hanford Site. Tritium concentrations greater than the MCL were detected in the 200 East and 200 West Areas, the downgradient portions of the 400 and 600 Areas, and scattered locations of the 100-D, 100-F, 100-K, and 100-N Areas. Tritium is a radioactive isotope of hydrogen. It replaces or exchanges with nonradioactive hydrogen atoms and thus becomes part of the water molecule. Because tritium exists as part of the water molecule, it moves with the groundwater and is virtually unaffected by the chemical and physical interactions with aquifer materials that retard the transport of many dissolved constituents.

Nitrate contamination in the unconfined aquifer reflects the extensive use of aluminum nitrate and nitric acid for decontamination and fuel reprocessing activities. Acid waste solutions are the primary contributors to nitrate plumes currently observed in groundwater. Like tritium, nitrate can be used to define the extent of contamination because it is present in so many waste streams and is highly mobile in groundwater. Nitrate contamination is present in all operational areas and in significant portions of the 600 Area. Nitrate concentrations greater than the MCL have been detected in all operational areas except the 100-B and 400 Areas.

Iodine-129 contamination of the groundwater is significant due to its long half-life (16 million years), low DWS (1.0 pCi/L), and its tendency for bioaccumulation. The main contributors to iodine-129 contamination in Hanford groundwater have been the long-term discharges to cribs from the 200 Area nuclear reprocessing facilities. Three extensive plumes of iodine-129 contamination originated from the Central Plateau liquid waste disposal facilities that received process wastewater.

5.10.2 Contaminant Transport Predictions

Tritium levels are predicted to drop below MCL in 50 years with the exception of the area surrounding the crib which receives treated water from the ETF. Tritium discharged in the ETF crib is not predicted to migrate beyond the Central Plateau at levels above the MCL. Additional field data are needed to refine the predictions in this area.

If the assumption that iodine-129 moves essentially with the water is correct, iodine-129 from all areas except the 200 West Area is predicted to disperse in 50 years. However, iodine-129 from the 200 West Area is predicted to decline in concentration as it moves under 200 East Area, but would still be above the MCL when it reaches the Central Plateau boundary in about 100 years. If a small interaction of iodine-129 with the soil is assumed (K_d = 0.3 mL/g), it would remain at concentrations exceeding the MCL in all areas for more than 200 years. Thus, the soil adsorption properties of iodine remain an important technical uncertainty at this point.

Nitrate is predicted to dissipate to below MCL concentrations within about 100 years in all areas except the Central Plateau. However, the nitrate plume currently centered in the 200 West Area would continue to expand eastward eventually covering much of the 200 East Area and extending well beyond the eastern boundary of the Central Plateau.

5.10.3 Initial Remediation Approach

Currently, remediation through natural attenuation of the sitewide plumes is proposed for interim action.

The total volume of groundwater containing greater than 20,000 pCi/L (the MCL) of tritium is approximately 5.3×10^{11} L (1.4×10^{11} gal), spread over approximately 190 km^2 (73 mi^2). In addition, some tritium plumes have already reached the river. The mass of tritium contained in that volume is relatively small, amounting to approximately 18 g (0.63 oz). Separation of tritium from groundwater is not practical with current technology. The contaminant predictions indicate that tritium will attenuate naturally to acceptable levels within a reasonably short time frame (<50 years). Remediation possibilities are limited to intercepting tritium near the area of discharge to the river (or other intermediate location) and returning the tritium to the Central Plateau where a longer travel time would allow the tritium to decay. However, it is currently believed that such actions would be very costly due to the size of the plumes and would therefore not be cost effective relative to a natural attenuation alternative. Treatment technology and disposal options for tritium are provided in *Tritiated Wastewater Treatment and Disposal Evaluation for 1995* (DOE-RL 1995e), which is updated annually. Evaluation of remedial options for tritium is being performed as part of the corrective measures study (CMS) for the 200-PO-1 Operable Unit (DOE-RL 1996b).

The volume and areal extent of water contaminated with iodine-129 places severe constraints on the ability of current technology to effectively remediate this groundwater problem. Iodine removal would be limited due to competing ion effects from other anions in groundwater. The ability to treat groundwater to the low concentrations required for reinjection has not been demonstrated (DOE-RL 1996c). Evaluation of remedial options for iodine-129 is being performed as part of the CMS for the 200-PO-1 Operable Unit (DOE-RL 1996b).

Nitrate occurs as a co-contaminant with nearly every other plume of concern on the Hanford Site. The only areas in which this is not the case include the relatively large plume found in the 100-F Area and in the 100-N Area that contains a nitrate plume outside of the strontium-90 plume. Initial remediation efforts to address other contaminants are generally not addressing nitrate. Nitrate remedial alternatives are being addressed as part of the CMS for the 200-PO-1 Operable Unit (DOE-RL 1996b). However, this evaluation is confined to the 200-PO-1 nitrate plumes and is not addressing the more problematic nitrate contamination in the 200 West Area or nitrate in other areas. It is recommended that remedial alternatives be developed to address the sitewide nitrate contamination problem, especially in the 200 West Area.

In summary, each of these large plumes needs to be examined in detail before a remedial approach can be specified. Although the size of the plumes may prohibit targeting remediation of all the contamination, individual segments of each plume may offer some opportunity and benefit for earlier action. To aid in remedial decision making for these and other Hanford contaminant plumes, a decision process (BHI 1997) has been developed as part of the effort to refine the groundwater remediation strategy. A summary of this decision process is provided in Section 5.12.

5.11 TREATMENT AND DISPOSAL OF TREATED GROUNDWATER

Aboveground treatment of contaminated groundwater must dispose of the treated water. Alternatives include the following:

- Reintroduction to the ground through aquifer reinjection or soil column disposal
- Discharge to the Columbia River
- Evaporation
- Water reuse.

Evaporation is discounted because of the projected high volumes of water coupled with the expected high energy use and its costs. Ideally, all contaminants can be reduced to levels below regulatory concern. However, in many cases, effective treatment is only feasible for the primary contaminants. The treatment of the remaining cocontaminants is often not possible or would significantly affect the feasibility of conducting the remediation.

It is recommended that treatment of groundwater have the objective of reducing both targeted and cocontaminants to levels below regulatory concern. However, should complete removal prove infeasible, the following criteria are recommended to determine a disposal location. The selected location should ensure the following:

- Not spread contamination into uncontaminated areas or impede the current and future cleanup effort

- Facilitate the containment and removal of contaminants, if possible

- Make use of existing liquid treatment and disposal facilities, as feasible

- Facilitate secondary usage of the treated effluent.

Establishing the location for the disposal of partially treated groundwater is key to the implementation of effective, large-scale containment and remediation systems and should be the focus of attention in the near future.

There are opportunities to optimize resources for treatment and disposal of effluent generated by CERCLA groundwater remediation activities and liquid effluent projects. The 200 Areas ETF and the TEDF are operational infrastructures that will be considered for future effluent treatment and/or disposal needs (Figure 5-1). The 200 Areas ETF is a 568-L/min (150-gal/min) mixed waste (low-level radioactive and RCRA waste) treatment facility and is available to treat other Hanford Site dilute aqueous waste in support of the Hanford Site environmental restoration mission.

5.12 DECISION PROCESS FOR IMPLEMENTATION OF THE GROUNDWATER REMEDIATION STRATEGY

This section describes a decision process for planning future investigations and remediation of contaminated Hanford groundwater to guide implementation of the groundwater remediation strategy.

Although significant progress is being made in addressing Hanford groundwater contamination, this process is intended to help guide the remainder of the remediation projects leading into final remedy decisions. The decision process defines the decision-making criteria to support future characterization and remediation planning. This should help to ensure that groundwater remediation goals are clearly identified, are met to the maximum extent practicable, and are conducted in a cost-effective manner. A more detailed discussion of the decision process is given in *Decision Process for Hanford Sitewide Groundwater Remediation* (BHI 1997).

The decision process presented here is based on a recognition that, although cleanup to MCLs remains a principal goal of the remediation projects, cleanup to these standards may not be achievable using currently available technology because of Hanford's contaminant characteristics and site conditions. It is therefore important that alternative approaches which are provided for in federal and state regulations be identified so that future investigation and remediation activities can be effectively planned with full consideration of final remediation goals.

5.12.1 Overview and Summary of the Decision Process

The decision process is applicable to investigations and remediation of any Hanford groundwater contamination. The decision process steps are shown graphically in Figure 5-2. A summary of the decision process is provided as follows. The steps referred to in the text refer to the elements of the flow diagram in Figure 5-2.

The steps of the decision process provide more detailed information on implementation of the general framework and strategies that have already been specified in the HPPS. Steps 1 through 5 describe in more detail the decisions and activities required to move from characterization through the IRM decision. Steps 6 through 10 describe implementation and evaluation details for the actual IRM implementation phases. Steps 11 through 14 describe the decisions and documentation requirements for specifying final remedies. The process described in these steps provides new and more detailed information that is consistent with the framework and principles of the HPPS.

Steps 1 through 5: Moving from site characterization through the IRM decision.

- Site characterization is conducted to determine the nature and extent of groundwater contamination.

- Monitoring is used to track the movement of plumes and the changing concentrations of contaminants at individual wells. Monitoring data are used to prepare trend plots of contaminant concentrations with time and to provide dose/risk impact information for protection of the river and downstream drinking water systems.

- Characterization and monitoring data are used to build and continuously refine the conceptual site model.

- Groundwater monitoring and characterization data are screened to categorize the plume and initially assess the need for remediation based on exceedance of regulatory standards.

- The plume is assessed for the availability of remedial technology. If no remedial technology is available (e.g., for tritium), the plume enters the final remedy decision pathway (Step 13) where natural attenuation is evaluated as a principal component of the final remedy. If remedial technologies are available, natural attenuation may still be an option if it will reduce contamination to acceptable levels in a time frame comparable to alternative remedial actions.

Institutional controls would also be a part of the final remedy in situations where a relatively long time frame is required before the contamination reached acceptable levels.

- The decision to conduct an IRM is determined according to criteria established in the HPPS. A focused feasibility study (FFS) is performed to select the remedy, but only if the remedy is not straightforward and multiple alternatives are available. Treatability studies are conducted if needed to provide data for design of remedies. The IRM decision is documented by the DOE in a proposed plan and interim record of decision (IROD) by the regulators. If an FFS is not performed, a streamlined evaluation of the alternative(s) against the nine CERCLA remedy selection criteria and the no-action alternative must still be documented. This can be done in either the proposed plan or other document that resides in the Administrative Record.

Steps 6 through 10: Implementation and evaluation of IRMs.

- The IRM is designed and implemented. Hydraulic pumping for plume containment is the presumed interim measure for most Hanford plume applications, although mass reduction and plume cleanup may also be objectives in some situations. Monitoring is performed to assess progress in containing the plume and/or reducing contaminant concentrations.

- The ability of the IRM system to contain the plume (to the extent specified in the IROD) is assessed. If containment is not achieved, the IRM system is modified until the specified degree of containment is achieved.

- The effects of the IRM on achieving cleanup are assessed. If concentrations are permanently reduced to meet cleanup standards, a final proposed plan and final ROD are issued for no further action.

- If cleanup standards are not met, the design of the IRM is assessed to determine whether design modifications could achieve cleanup. If there is a potential to achieve cleanup through design changes, these changes are implemented and the effects of the changes on cleanup are assessed.

- Data from the monitoring of the contaminants of concern are trend plotted. Pump-and-treat and monitoring are continued until the trend plots indicate that the IROD values are reached or an asymptotic effect is observed. When contaminant concentrations are not declining significantly (asymptote reached), the presence of continuing contamination sources is assessed. If continuing contamination sources are present, these are removed or isolated to the maximum extent practicable.

Steps 11 through 14: The final remedy decision process.

- The final remedy decision must assess whether the groundwater is a potential future source of drinking water and/or impacts surface water use or ecological resources. According to EPA classification and Ecology regulations, most Hanford groundwater is a potential future source of drinking water source by definition. The only exception is a deep aquifer in the vicinity of the 400 Area where natural fluoride levels make the water unfit for use as drinking water.

- The ability of natural attenuation to meet cleanup goals is evaluated through modeling and monitoring. If predicted natural attenuation will not meet cleanup goals within a time frame where groundwater use is controlled and groundwater is classified as a potential future source of drinking water or discharges to the river will impact river use or ecological resources, then either plume containment must be continued, if technically practicable, or institutional controls must be in place at the point(s) of exposure. Institutional controls are maintained until contaminant concentrations have attenuated to acceptable levels.

- If technical impracticability of cleanup through active remediation has been demonstrated, some combination of natural attenuation, containment (if technically practicable), and institutional controls will likely be components of the final remedy. An FFS is prepared if needed to document the technical data supporting the determination of technical impracticability. Cumulative risks are assessed for contamination that remains prior to implementation of the final remedy.

- The final proposed plan and ROD are prepared to document the final remedy decision. The final ROD may include a no further action decision or establishment of alternate concentration limits (ACL) or ARAR waivers for those contaminants that could not be cleaned up to meet the standards. Establishment of ACLs as a final action is possible only if the plume can be contained at the existing leading edge. If not, ARAR waivers remain the only option.

5.13 IMPLEMENTATION OF A GROUNDWATER REMEDIATION STRATEGY

The groundwater remediation strategy provides direction for cleanup. It purposefully builds on past achievements, commitments, programs, and plans. The strategy direction can be phased in at the operable unit level at a pace consistent with facilitating remediation while minimizing disruption of scheduled activities.

The value of this strategy to the implementing program is that it provides an opportunity to assess past achievements and efforts while refining and proposing a new course of action. To the organizations outside the implementing program, the strategy presents a summary of the remediation program and its direction and thus allows for improved coordination.
A management-level coordinating group should be designated to facilitate the interaction between the remediation program and other program elements involved with liquid and solid waste disposal.

As remediation proceeds, reporting the effectiveness of the groundwater remediation effort, changes in approach, and understanding of successes and failures becomes increasingly important. The following three recommendations are made:

1. Interim goals be established to allow evaluation of progress

2. Preparation of an annual report summarizing and evaluating program progress

3. Prioritization of remediation efforts be coordinated by a group consisting of internal and external organizations and stakeholders impacting and being impacted by liquid effluent management and cleanup activities at the Hanford Site.

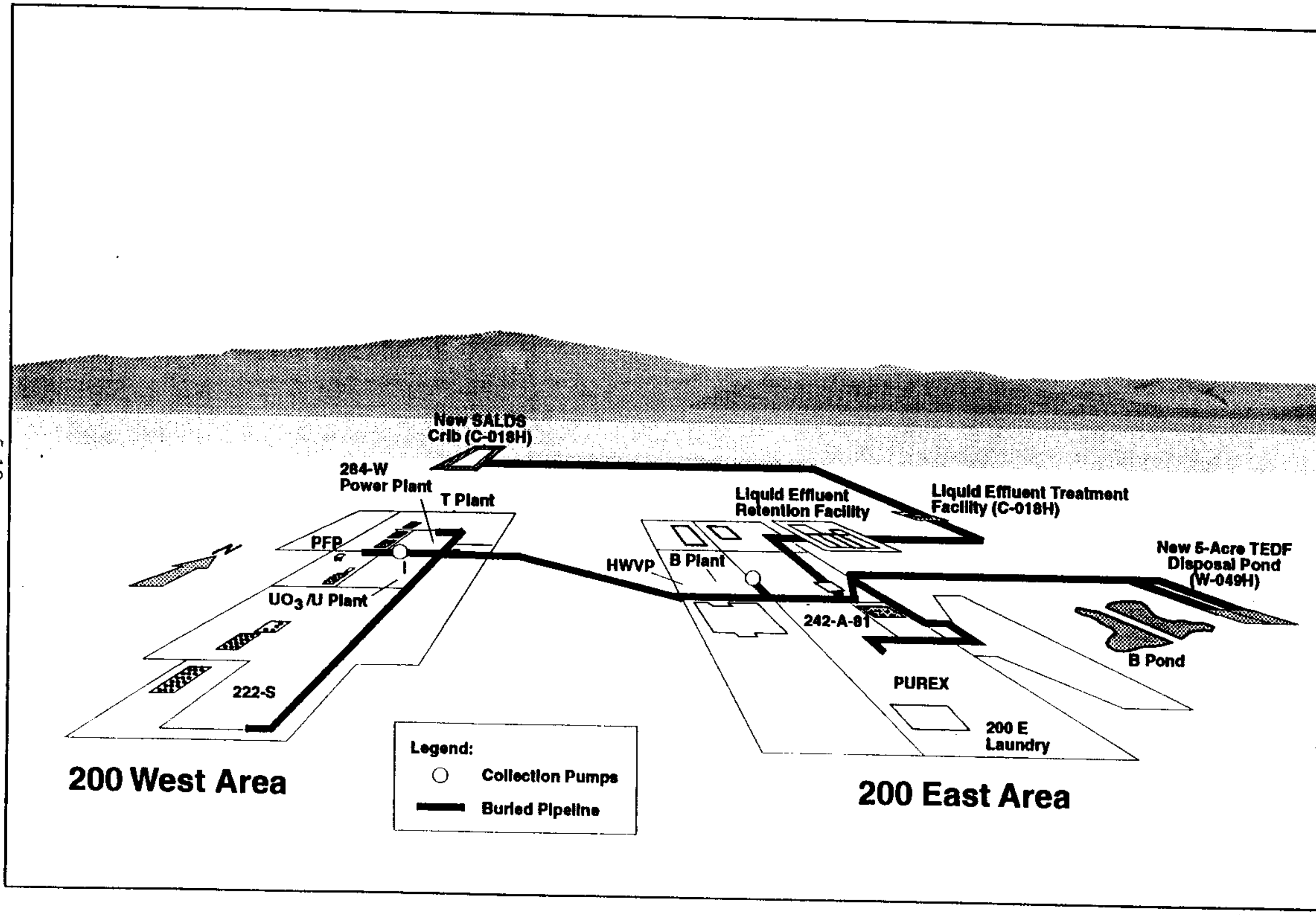


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Figure 5-1. 200 Areas Effluent Treatment Facility, Collection, and Disposal Network.

Figure 5-2. Decision Process Flow Diagram.

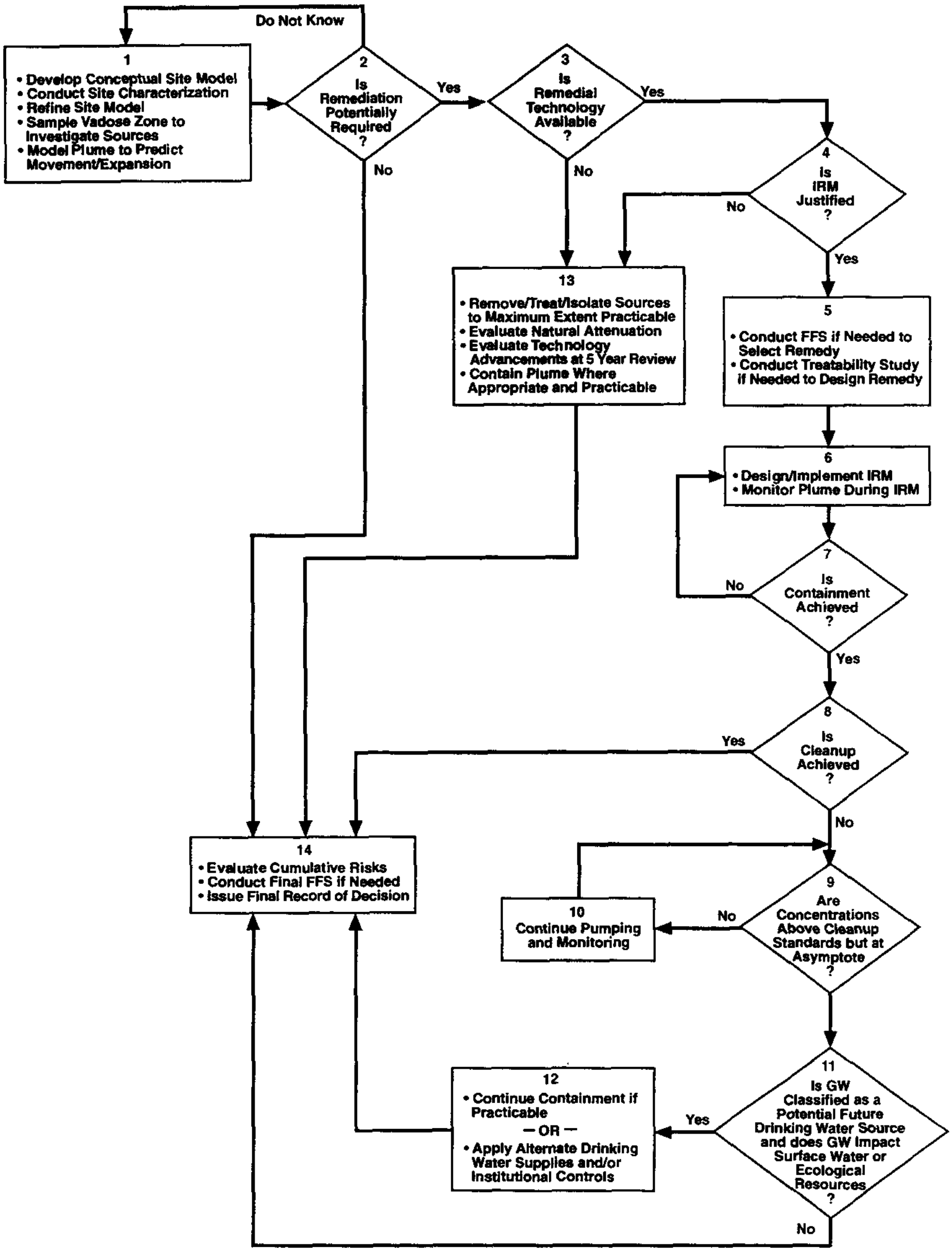

Table 5-1. Major Contaminant Plumes and Cleanup Approach.

Plume	Facility	Location	Initial Cleanup Approach
Uranium and technetium-99	$U0_3$ Plant	Central Plateau (200 West Area)	Containment and mass reduction of high-concentration areas
Organic (carbon tetrachloride, trichloroethylene, and chloroform)	PFP	Central Plateau (200 West Area)	Containment and mass reduction of high-concentration areas
Combined plutonium, cesium-137, and strontium-90	B Plant (B-5 reverse well)	Central Plateau (200 East Area)	No interim action required (plutonium is substantially immobile and cesium-137/ strontium-90 will decay before reaching plateau boundary)
Technetium- 99 and cobalt-60	BY Cribs	Central Plateau (200 East Area)	No interim action (effective means of plume remediation is not currently available)
Strontium-90	N Reactor	Reactor areas (100-N)	Remediation[a]
Chromium	D Reactor H Reactor K Reactor	Reactor areas (100-D, 100-H, and 100-K)	Remediation

PFP = Plutonium Finishing Plant.
UO_3 = Uranium Trioxide (Plant).

[a] Groundwater remediation refers to the reduction, elimination, or control of contaminants in the groundwater or soil matrix to restore groundwater to its intended beneficial use and/or to protect the Columbia River.

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APPENDIX A

PRELIMINARY REMEDIAL DESIGN APPROACH FOR THE 200 WEST AREA CARBON TETRACHLORIDE PLUME

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FIGURES

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A1.0 INTRODUCTION

A1.1 PURPOSE

This appendix presents the preliminary remedial design and cost estimate for intercepting the carbon tetrachloride (CCl_4) groundwater plume in the 200 West Area (Figure A-1). The plume is moving eastward from the vicinity of the cribs associated with the Plutonium Finishing Plant. The primary performance objective of the remediation system would be to contain the carbon tetrachloride plume within the Hanford Future Site Uses Workgroup (HFSUWG) boundary for the 200 Area (HFSUWG 1992).

A1.2 NATURE AND EXTENT OF CONTAMINANTS - OVERVIEW

The fate of approximately two-thirds of the total quantity of the CCl_4 discharged to soils is unknown (Rohay 1994). Liquid and vapor CCl_4 is present in the vadose zone, and soluble and dense nonaqueous phase liquid (DNAPL) CCl_4 are present in the groundwater. Due to these characteristics, there is likely to be a long term source of CCl_4 to groundwater for years to come.

The hydraulic gradients were artificially high during plant operations due to the "mounding" of process water infiltrating from the surface. These gradients are now decreasing over time, slowing the rate of plume migration since the cessation of discharges of process water to the cribs.

In 1995 and 1996, a sitewide groundwater-contaminant transport model was developed (BHI 1996) to predict the movement of contaminants across the Hanford Site. The movement of the CCl_4 plume in the 200 West Area was modeled for several scenarios which included varying source-to-groundwater discharge rates and CCl_4 retardation factors. One scenario included a pump and treat system targeted at the highest CCl_4 concentrations in the center of the plume. This model predicted that the CCl_4 plume would eventually migrate beyond the HFSUWG boundary for all scenarios evaluated.

A1.3 REMEDIATION CONCEPT

The type of contamination problem would usually justify the analysis of multiple technologies and configurations to optimize system performance and cost. For the purpose of this appendix, the pump and treat technology has been selected as the base case for this evaluation. If and when a remediation concept is initiated, other technologies should be evaluated to achieve optimal performance and cost.

The systems selected for this estimate includes the following components:

- Groundwater extraction wells
- Conveyance to a treatment system
- Groundwater treatment
- Conveyance to disposal
- Injection wells.

The methodology for preparing this estimate as well as descriptions of the remediation system components are described in the following sections.

A2.0 METHODOLOGY

A2.1 SYSTEM CONFIGURATION

In order to prevent the CCl_4 plume from migrating past the HFSUWG boundary, the extraction wells would need to be located close to the leading edge of the plume with the injection wells located upgradient of the plume. This would create a recirculation cell which would force the CCl_4 plume to move to the east where it would be captured and treated.

A2.2 WELL SPACING

Although the sitewide model (BHI 1996) was used to predict the effects of pumping at the center of the plume, it cannot be used to predict the effects of a line of wells at the leading edge of the plume because the nodal spacing for the sitewide model had to be coarse to simulate groundwater flow across the entire Hanford site. This precluded using the sitewide model for relatively small- to medium-scale remedial actions. Therefore, an analytical capture zone analysis (Keely and Tsang 1983; Javendel and Tsang 1986) was used to estimate the number of pumping wells needed.

For the CCl_4 plume in the 200 West Area, the following assumptions were made for the capture zone analysis:

1. The leading edge of the plume would be defined as the 5 ppb isopleth (Figure A-1). The location of this isopleth is inferred from well data. The exact location of this isopleth is unknown. Therefore the pumping would take place between the 5 ppb and 100 ppb isopleths (Figure A-1).

2. The width of the of the plume, aligned north to south, in this area is approximately 3,300 m (10,830 ft).

3. Water would be treated and injected into a line of wells approximately 3,550 m (11,650 ft) west and upgradient from the center of the CCl_4 plume. This line of wells would also be aligned north to south

4. The ratio between pumping wells to injection wells would remain the same as the present 200-ZP-1 Pump-and-Treat operations (6 pumping and 5 injecting wells)

5. The hydraulic gradients at the line of pumping wells vary from 0.001 m/m to 0.006 m/m (0.001 ft/ft to 0.006 ft/ft); in the area of the injection zones the gradient range from 0.0001 m/m to 0.001 m/m (0.0001 ft/ft to 0.001 ft/ft). A gradient of 0.002 m/m (0.002 ft/ft) was used for the capture zone analysis and a gradient of 0.0009 m/m (0.0009 ft/ft) was used for the injection zone. Higher gradients require tighter well spacing (i.e., if a hydraulic gradient of 0.004 m/m [0.004 ft/ft] was used, more wells would be needed)

6. Water is withdrawn at a rate of 190 L/min (50 gal/min) per well at the pumping wells, and injected back into the aquifer at a rate of 225 L/min (60 gal/min) per well at the injection wells.

7. The hydraulic conductivity is 15 m/d (50 ft/d), the thickness of the aquifer is 46 m (151 ft), the effective porosity is 0.2. For the injection wells the aquifer thickness is 48 m (157 ft).

A spreadsheet program was prepared, using the above assumptions, to calculate a capture zone (Keely and Tsang 1983; Javendel and Tsang 1986) and the optimum distance between two wells. The results of the pumping well calculations are shown in Figure A-2, with the results from the injection well calculation shown in Figure A-3. These figures show input values, conversions, and the results from the calculation along with a plot of a single well capture zone. The optimum distance creates a stagnation point (i.e., a point in which the flow velocities go to zero between the two wells). If the well spacing is too close together, an overestimate of the number of wells needed is made, and the cost goes up correspondingly. However, if the well spacing exceeds the optimum distance, the plume will not be captured. Additionally, the portion of the plume that lies between the wells and beyond the optimum distance between the wells, has the potential for its movement to be accelerated.

The results from this spreadsheet calculation indicate the optimum well spacing for the pumping wells would be approximately 75 m (245 ft), while the injection wells spacing should be approximately 190 m (625 ft). The differences between the size and shape of the capture zone and injection zone are due to the difference in both the hydraulic gradient between the two areas and the difference between the pumping and injection rates. Dividing the optimum distance between wells over the total width of the plume near the leading edge indicates that approximately 44 pumping wells are needed.

By using the ratio of pumping wells to injection wells for the present 200-ZP-1 Pump and Treat system, 37 injection wells are needed. Using the present ratio of pumping wells to injection wells yields a greater number of injection wells than injection zone analysis indicates. This could affect the regional hydraulic gradients in this area which in turn could affect the size of the capture zones. Since the gradients would be increasing due to injection upstream of the pumping wells, the optimum distance between wells would decrease, thereby, necessitating more pumping wells. The results of this calculation are shown in Figure A-4. Overlaid on this figure are the carbon tetrachloride isopleths, the pumping wells at 75 m (245 ft) centers (black circles), injection wells at 190 m (625 ft) centers (open squares), and every third capture zone and injection zone.

The capture and injection zones shown in Figure A-4 are for a single well for illustrative purposes only.

This analysis is a first approximation only. If this becomes a viable remediation alternative, a more refined modeling approach should be planned. The results from this analysis would be used as a starting point for that more refined approach.

A3.0 TREATMENT FACILITY DESCRIPTION

This section presents a preliminary treatment design and cost estimate based on the design methodology discussed in Section A2.0. The facility will have a total capacity, with all units in service, of 9,463 L/min (2,500 gal/min). An additional 1,136 L/min (300 gal/min) capacity is included for operational flexibility. The treatment system will use an air stripping system similar in type to the 200-ZP-1 Pump and Treat facility. All well water extraction and injection piping will be double wall high density polyethylene (HDPE) and will be buried with minimum 0.9 m (3 ft) of cover for freeze protection. For this estimate, it was assumed that none of the pipeline routes cross areas restricted in use by either cultural resource sites or waste sites.

A4.0 TREATMENT TRAIN DESCRIPTION

Starting at the extraction well, pumping and treatment facilities are as follows:

1 Each extraction well will include a submersible pump. The pump motors will all have adjustable frequency drives (AFD) to allow control of extraction well pump discharge.

2. Separate pipelines, 7.5 cm (3 in.) in diameter, will lead from the extraction well to an influent tank. To minimize the amount of equipment (e.g. flowmeters, sample valves) that is located at the wellhead, it was assumed that the individual well discharge pipelines will extend from the well head to the influent tank. The average length of these pipes is estimated as 1,300 m (4,265 ft). The influent tank (or tanks) will be located in the treatment facility building. A second assumption is that convenience sampling and flow

monitoring of water from each well is required. Manual valves at the influent tank will allow sampling from each well. Flowmeters, located at the influent tank, will allow the flow rate from each well to be monitored.

3. The influent tank will have a minimum of two horizontal centrifugal pumps with AFD for their motors. These pumps will deliver water from the influent tank to a stripping tower unit. Pumps will be controlled to maintain a constant level in the influent tank. The tank volume provides operational flexibility.

4. Air stripping tower units will be centrally located at the treatment building just west of the extraction well field. The towers with associated activated carbon canisters, fans, electrical, instrumentation, and piping will be housed in a metal-skin, insulated building.

5. Effluent from the air stripping tower sump will be pumped into an effluent tank. A minimum of two effluent pumps will be provided. The stripping tower effluent pumps shall be constant speed.

6. A minimum of two pumps will be provided to move water from the effluent tank to the injection well heads. These pumps will have AFD drives. Flowmeters will be used to monitor instantaneous flow and cumulative flow volumes through the treatment train.

7. The treatment train effluent will be pumped through 20 cm (8 in.) diameter double-walled header pipes. Each header pipe will serve approximately 7 injection wells. The average length of these effluent pipes is estimated as 3,200 m (10,500 ft). The 20 cm (8 in.) pipe will extend to a point east of the injection wells where individual 7.5 cm (3 in.) diameter pipelines will extend to the injection wells. Flowmeters will be used to monitor the rate and cumulative volume of water delivered to each injection well.

A5.0 COST ESTIMATE

This analysis is an order of magnitude cost estimate. The final cost of the project will depend on actual labor and material costs, actual site conditions encountered, productivity, competitive market conditions, final project scope, and construction schedule. All costs are in 1997 dollars. No escalation factor was used for future years. A contingency cost of 15 percent was added to the estimated costs for unidentified construction items. At this point in the project, this amount of contingency should be considered a minimum.

Construction costs were estimated based on preliminary locations for extraction wells, injection wells, and treatment facilities (see Section A2.0). Well costs were estimated based on drilling experience in the 200 Area and a completion depth of 82 m (270 ft). Treatment facility costs were estimated based on cost information available for a 1,893 L/min (500 gal/min) air stripping facility at 200-ZP-1. Construction costs were based on the use of a single, 9,463 L/min (2,500 gal/min) treatment facility. Final configuration of the number and size of pumping and treatment facility trains may vary as groundwater modeling and equipment costs become available.

Engineering and construction costs are summarized in Table A-1. Operation and Maintenance (O & M) costs estimates are presented in Table A-2. The O & M, estimates are based on annual costs. Both tables are summarized below:

Construction Costs (Includes D&D and G&A Costs @ 22.4%)	**$19,708,000**
- 9,463 L/min (2,500 gal/min) Air Stripper Treatment Facility (using 7/10 rule on 200-ZP-1 costs)	$12,883,000
- Well Drilling	$6,825,000
Engineering Costs (Incudes D&D and G&A Costs @ 22.4%)	**$5,344,000**
- Treatment Facility	$4,725,000
- Wells	$ 619,000
Subtotal	**$25,052,000**
Contingency (15%)	**$3,758,000**
Total Project Costs	**$28,810,000**
Total Annual O&M Costs	**$3,095,000**
- Annual O&M	$1,853,000
- Management/Oversight (at 67% of operational cost)	$1,242,000

A6.0 REFERENCES

BHI, 1996, *Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions*, BHI-00469, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

HFSUWG, *1992, The Future Uses for Hanford: Uses and Cleanup,* Letter Report to Ms Dana Rasmussen (EPA), John Wagoner (RL-DOE), cc: Fred Olson (Washington Department of Ecology) From Hanford Future Site Uses Working Group, date December 22, 1992

Javendel, I., and C. F. Tsang, 1986, "Capture Zone Type Curves: A Tool for Aquifer Clean-Up," *Ground Water*, Vol. 24, pp. 616-625.

Keely, J. F., and C. F. Tsang, 1983, "Velocity Plots and Capture Zones of Pumping Centers for Groundwater Investigations", *Ground Water*, Vol. 21, pp. 701-714.

Rohay, V. J., 1994, *1994 Conceptual Model of the Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site*, WHC-SD-EN-TI-248, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Figure A-1. Carbon Tetrachloride Plume Overlaid on the Water Table Elevations in the 200 West Area.

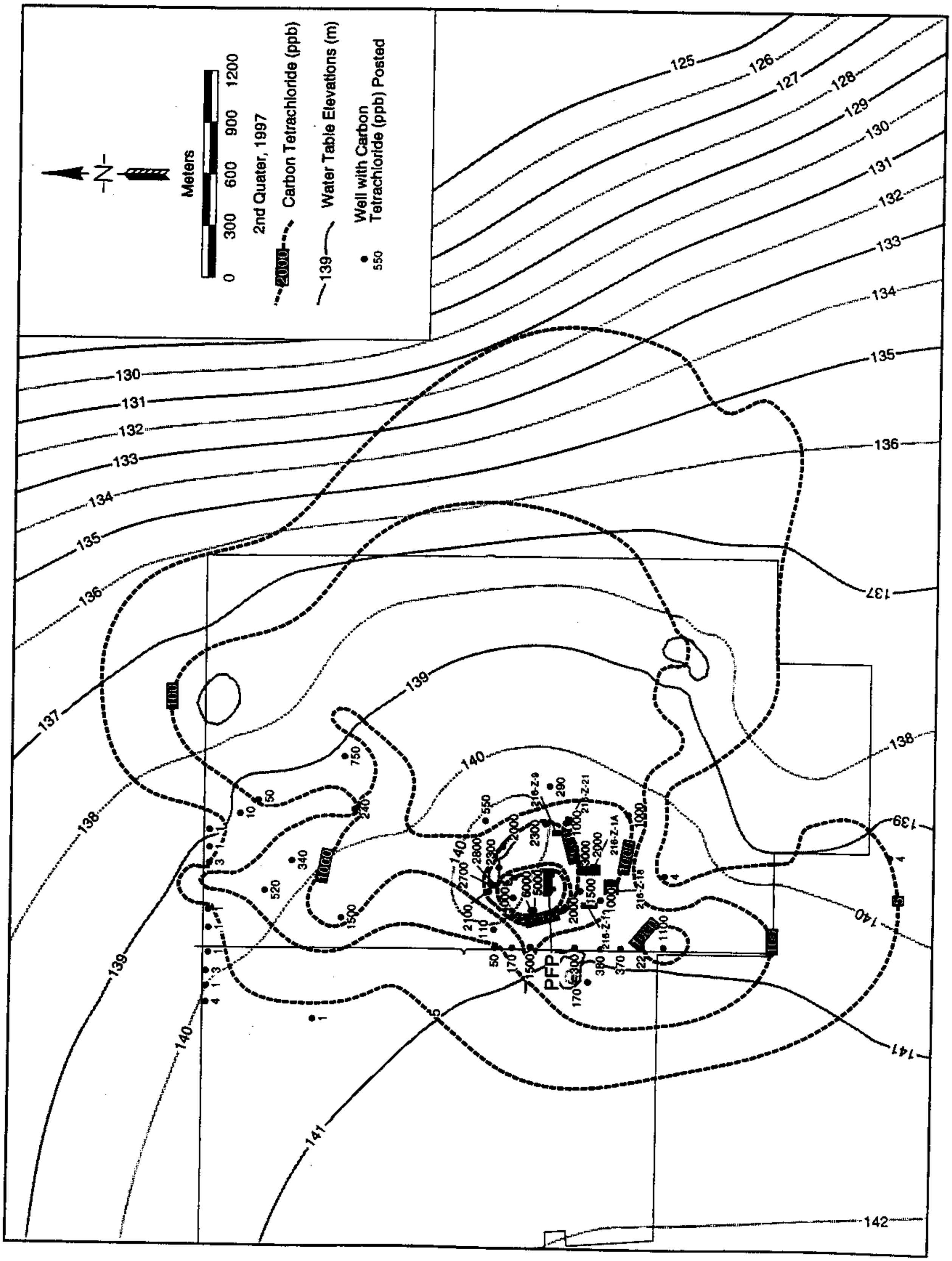


Figure A-2. Capture Zone Analysis for the 200-ZP-1 Carbon Tetrachloride Plume.

CAPTURE ZONE ANALYSIS

Keely and Tsang, 1983

Javendel and Tsang, 1986

200-ZP-1 Carbon Tetrachloride (Capture Zone)

INPUT DATA					
Thickness:	150	ft	Gradient:	0.002	ft/ft
K:	50.0	ft/d	Porosity:	0.2	
Q:	50	gpm			
WORK AREA/CONVERSIONS					
T:	7.50E+03	ft^2/d	Velocity	5.00E-01	ft/d
T:	5.21E+00	ft^2/min	Q:	9.63E+03	ft^3/d

RESULTS			DESCRIPTION
Stagn. pt:	102.1	ft	Dist. downgradient to stagnation point
Width:	641.7	ft	Max. width of capture zone (upgradient)
Dist. Max:	10107	ft	Dist. upgradient to max. width

Number of Pumping Wells n	Distance Between Dividing Streamlines at the line of wells (ft) nQ/2TI	Optimum Spacing (ft)	Capture Zone Distance at line of wells (ft)
1	320.86		321
2	641.71	204	525
3	962.57	257	836
4	1283.42	245	1056
5	1604.28	245	1301
6	1925.13	245	1546
7	2245.99	245	1792
8	2566.84	245	2037
9	2887.70	245	2282
10	3208.56	245	2527
11	3529.41	245	2772

References:

Javendel, I. and Chin Fu Tsang, 1986. *Capture-Zone Type Curves: A Tool for Aquifer Cleanup, Ground Water. Vol.* 24, No. 5, pp 616-625.

Keely, J and Chin Fu Tsang, 1983. *Velocity Plots and Capture Zones of Pumping Centers for Ground-Water Investigation* Vol. 21, No. 6, pp 701-714.

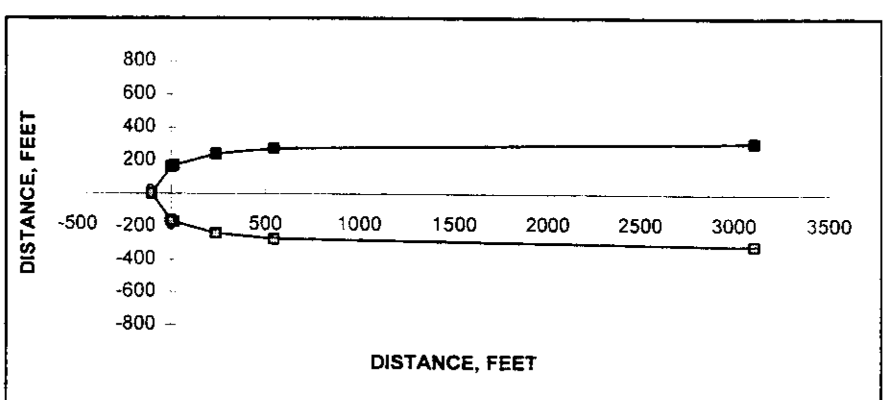


Figure A-3. Injection Zone Analysis for the 200-ZP-1 Carbon Tetrachloride Plume.

Keely and Tsang, 1983

Javendel and Tsang, 1986

200-ZP-1 Carbon Tetrachloride (Injection Zone)

INPUT DATA					
Thickness:	155	ft	Gradient:	0.0009	ft/ft
K:	50.0	ft/d	Porosity:	0.2	
Q:	59.5	gpm			
WORK AREA/CONVERSIONS					
T:	7.75E+03	ft^2/d	Velocity	2.25E-01	ft/d
T:	5.38E+00	ft^2/min	Q:	1.15E+04	ft^3/d

RESULTS			DESCRIPTION
Stagn. pt:	261.4	ft	Dist. downgradient to stagnation point
Width:	1642.2	ft	Max. width of capture zone (upgradient)
Dist. Max:	25865	ft	Dist. upgradient to max. width

Number of Pumping Wells n	Distance Between Dividing Streamlines at the line of wells (ft) nQ/2TI	Optimum Spacing (ft)	Capture Zone Distance at line of wells (ft)
1	821.11		821
2	1642.23	523	1344
3	2463.34	659	2138
4	3284.46	627	2703
5	4105.57	627	3330
6	4926.69	627	3958
7	5747.80	627	4585
8	6568.91	627	5212
9	7390.03	627	5839
10	8211.14	627	6467
11	9032.26	627	7094

References:

Javendel, I. and Chin Fu Tsang, 1986. *Capture-Zone Type Curves: A Tool for Aquifer Cleanup. Ground Water. Vol.* 24. No. 5, pp 616-625.

Keely, J. and Chin Fu Tsang, 1983. *Velocity Plots and Capture Zones of Pumping Centers for Ground-Water Investigations* Vol. 21, No. 6, pp 701-714.

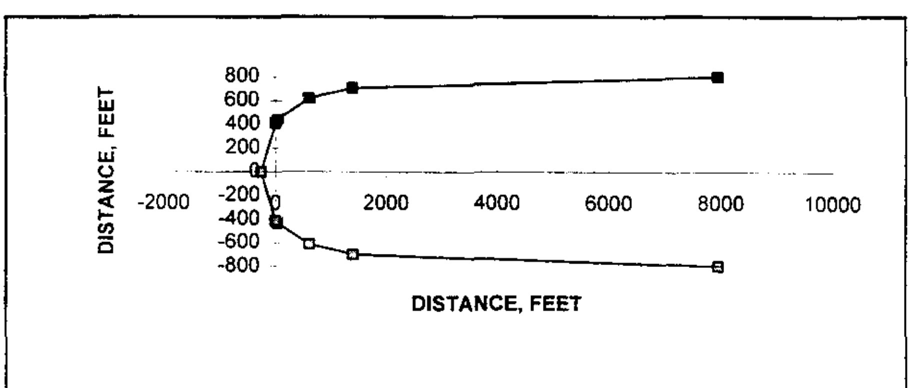
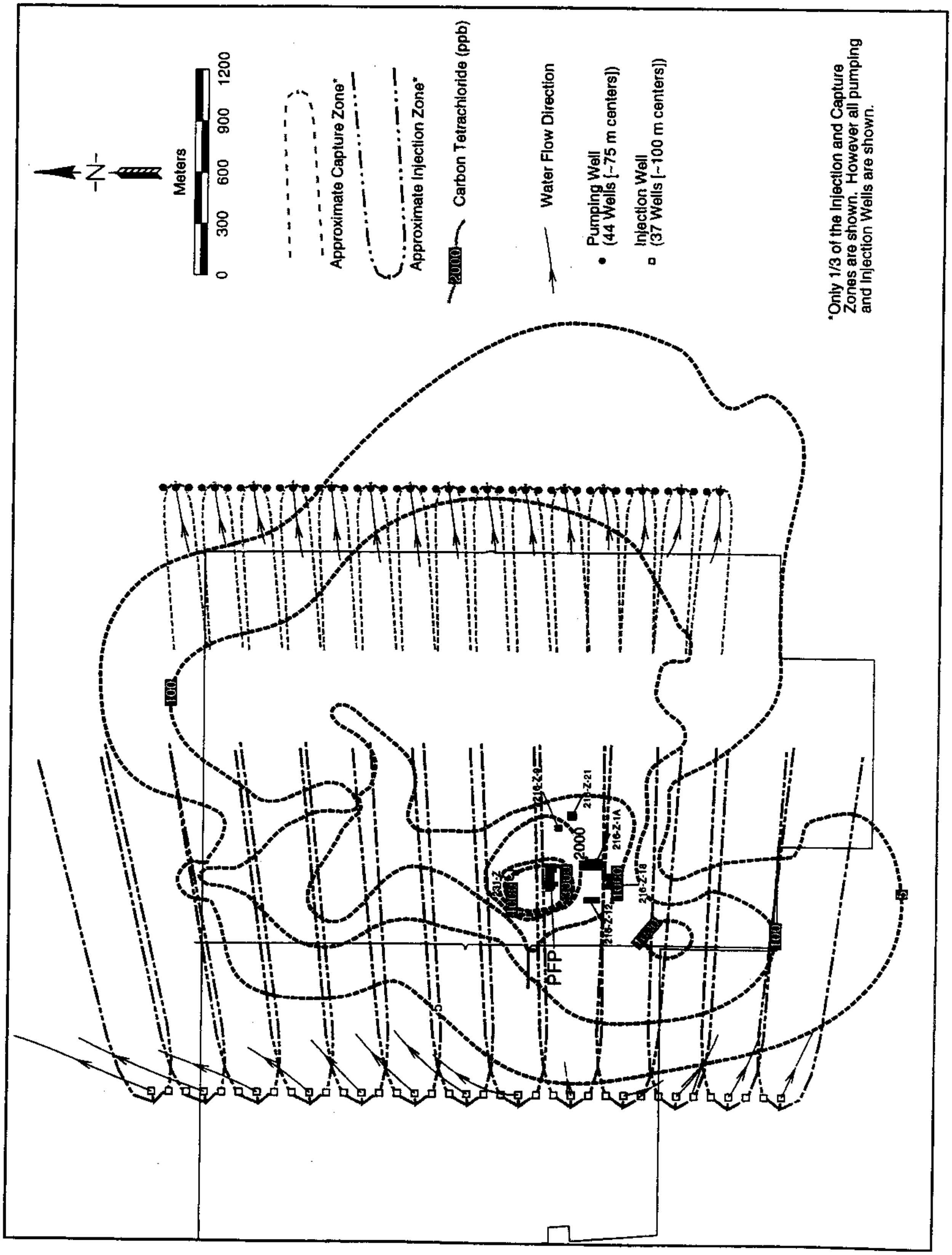


Figure A-4. Capture and Injection Zones Overlaid on the Carbon Tetrachloride Plume in the 200 West Area.



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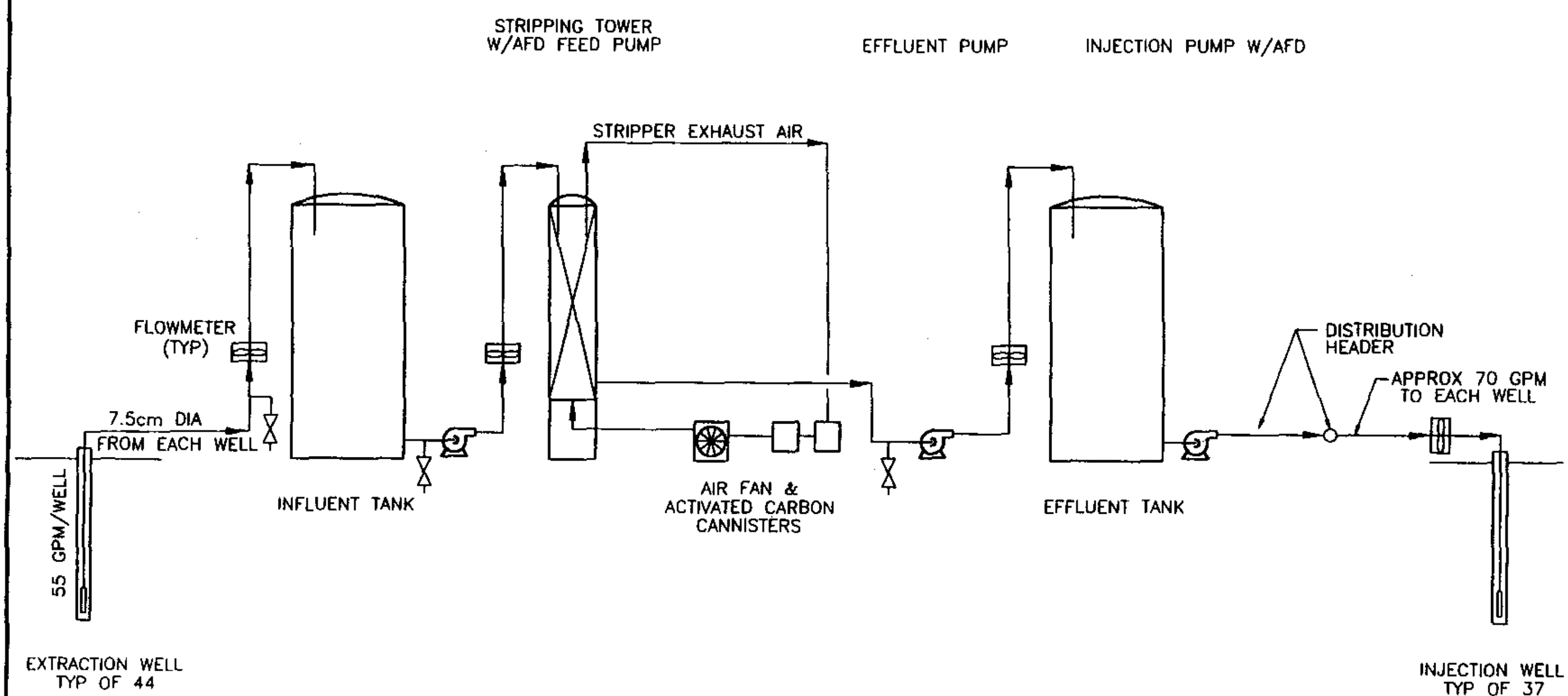

U.S DEPARTMENT OF ENERGY DOE FIELD OFFICE, RICHLAND HANFORD ENVIRONMENTAL RESTORATION PROGRAM	TYPICAL TREATMENT TRAIN

Figure A-5. Typical Treatment Train.

Table A-1. Engineering Cost Estimate for 9,463 L/min (2,500 gal/min) Pump and Treat with Air Stripping.

Contracts Let for 200-ZP-1	Construction Costs	D&D @ 18.49% G&A @ 3.89%	Subtotal	New ERC Costs	Total
DESIGN & PROCURE					
Foundations	$ 340,000				
Mechanical	$ 536,815				
Buildings	$ 252,598				
Install Balance of Plant	$ 255,442				
Install Flowlines	$ 417,177				
Pipe & Leak Detection Material	$ 122,000				
Change Order to Design	$ 34,982				
Change Order to Install	$ 71,782				
Phase III	$ 788,554				
Extr. Well Pump & VFD (mtl only)	$ 24,000				
SUBTOTAL CAPITAL COSTS	$ 2,843,350				
20% Change Orders & Misc	$ 568,670				
TOTAL COSTS	$ 3,412,020				
Cost is for one large 9,463 L/min (2,500 gal/min) unit					
Use 7/10 rule w/o ERC Labor					
3,412,020(2500/500)^0.7	$ 10,526,659	$ 2,355,866	$ 12,882,526		$ 12,882,526
ERC COSTS (FY 94, 95, 96)	$ 3,150,000	Included			
Use 1.5 times above number	$ 4,725,000	Included		$ 4,725,000	$ 4,725,000
NEW WELL COSTS					
81 New Wells					
81 x 270 Linear Feet (LF) = 21,870 LF					
x $255/LF (Driller only)	$ 5,576,850	$ 1,248,099	$ 6,824,949		$ 6,824,949
ERC Labor 5.14 People/One Yr				$ 618,840	$ 618,840
TOTAL	$ 16,103,509	$ 3,603,965	$ 19,707,475	$ 5,343,840	$ 25,051,315
CONTINGENCY 15%					$ 3,757,697
PROJECT TOTAL					$ 28,809,012

Table A-2. O&M Cost Estimate for 9,463 L/min (2,500 gal/min) Pump and Treat with Air Stripping.

1. POWER COSTS

Assumptions:
a. \$0.05 per kw-hr
b. 24 hr/day operation
c. 90% motor efficiency
d. All equipment on line

Extraction Wells	Connected HP
44 extraction wells on line	
57 gpm from each well with	
200 ft of TDH	
5 HP per well pump	220 HP

Air Stripper Treatment	Connected HP
Influent Pumps - 2,500 gpm @ 50 ft TDH	50
Stripper Fans	25
Effluent Pumps - 2,500 gpm @ 30 ft TDH	25
Injection Transfer Pump - 500 gpm @ 100 ft TDH	100
Estimated total treatment HP for 2,500 gpm	200 HP

Miscellaneous building loads
Such as exhaust/circulation fans, lights, and heating and cooling. Assume as 10% of other loads. 40 HP

Total Connected HP load = 460 HP

	per day	per yr
Total Kw-Hr =	9151	3,340,091

Annual Power Cost = \$167,000

2. LABOR COSTS

Assumptions: \$60 /hr
a. Total of 8 full time (3 supervisors, 5 operators) 2080 hr/yr
3 supervisors, 3 day shift, 1 swing, 1 graveyard. \$124,800 /employee annually
b. No sampling & testing costs included
c. No well redevelopment costs included

Annual Labor Cost = \$998,400

3. MATERIAL COSTS

Assumptions:
a. Annual pump and treat materials cost estimate as 2% of construction costs.
0.02 x \$19.4M = \$ 388,000
b. Treatment does not include pH adjustment

Annual Materials Cost = \$388,000

4. PERFORMANCE MONITORING

Assumptions:
a. Includes process sampling and plume monitoring, reporting, and waste handling

Annual Performance Monitoring cost = \$300,000

TOTAL ANNUAL O & M COSTS = \$1,853,400

APPENDIX B

ESTIMATED COSTS FOR PLUME TRACKING OVER THE NEXT 200 YEARS

TABLE OF CONTENTS

FIGURES

TABLES

B1.0 INTRODUCTION

A scoping level estimate of "mortgage" costs required to track and define the CCl_4, uranium and technetium-99 plumes to the Hanford Future Site Uses Working Group (HFSUWG) boundary through the next 200 years is presented in this appendix. Groundwater monitoring costs provide one piece of information that can be used for planning remediation approaches, whether passive or active, and in weighing the overall advantages or disadvantages of each approach. By implementing remediation efforts at certain critical times, remediation costs may be reduced significantly for the long-term.

Based on the results of the predictive modeling report (BHI 1996) most of the 200 Area contaminant plumes are not expected to migrate significantly past the future uses site working group boundary over the next 200 years (Figure B-1). The most notable contaminant plume in areal extent is the CCl_4 plume. Contaminant concentrations above the MCL appear to move just beyond the HFSUWG boundary at 200 years (Figure B-1). This plume therefore, represents the most significant for cost remediation and monitoring.

The following sections discuss how the cost estimates for the next 200 years were formulated, including the approach used to estimate the costs; the assumptions underlying the evaluation; the size and configuration of the monitoring network; the estimated costs for this effort; and some conclusions regarding how this scoping effort could be improved. Groundwater monitoring costs only address those needed for sample collection, laboratory analysis, and coordination of sampling activities.

B1.1 APPROACH

To determine costs for monitoring over the next 200 years a map was generated showing the extent of the plumes to the MCL at 50, 100, and 200 years. Overlaid on the map are the 1997 Hanford site groundwater monitoring wells. From this overlay the number of wells needed to track and define the plumes for each time period were qualitatively selected. The costs for sample collection, laboratory analysis and coordination of these activities were then calculated based on the number of wells selected, sampling costs predicated on current CERCLA groundwater sampling, and adjusted for a 4.0% inflation rate. Because the CCl_4 plume represents the most areally significant plume, it was assumed, as a worst-case scenario, that all three analytes (CCl_4, uranium and technetium-99) would be sampled and analyzed at all wells. In fact though, the overall number of wells that need to be sampled for uranium and technetium-99 is much smaller.

B1.2 ASSUMPTIONS

For this scoping analysis the following assumptions were used.

- The number of wells used in the monitoring network are divided into three groups based on 50, 100, and 200-year time increments. These time increments are the same as those used for the sitewide contaminant predictive model (BHI 1996). These intervals also represent periods of time where plume size changed most significantly.

- Costs estimates include those for the three main constituents CCl_4, uranium, and technetium-99 and are applied to all wells.

- The CCl_4 plume is considered a worst-case scenario because of the much larger area it covers at the end of the 200 year evaluation period. In actuality, costs for uranium and technetium-99 will be lower because of the fewer required samples (wells).

- Only costs associated with sample collection, laboratory analysis/reporting, and coordination of the sampling activities is included in the cost estimate. Regulatory or other reporting requirements is not included.

- Only existing wells are considered as part of the monitoring network. No new wells are planned for installation.

- Samples will be collected yearly.

- Costs are given in both 1997 dollars and present worth analysis, adjusting for a 4% inflation rate.

B1.3 SIZE OF THE MONITORING NETWORK

The number of wells required to monitor the plumes is based on the extent of the plume at 50, 100, and 200 years as defined in the *Hanford Sitewide Groundwater Remediation Strategy – Groundwater Contaminant Predictions* (BHI 1996). The number of wells used for each monitoring period was determined qualitatively, and only existing wells were used. A more rigorous approach could be applied, if desired, using a geostatistical model. It is anticipated that fewer wells would be required in the monitoring network if a statistical analysis is performed.

During the initial monitoring period (0 to 50 years) it is estimated that about 75 wells are needed to track and define the plumes. From 50 to 100 years, another 30 wells are required. And from 100 to 200 years, 15 more wells should be added, bringing the total to 120 wells for the entire 200 year period. Figures B-2, B-3, and B-4 show a possible monitoring well network for these periods, respectively.

B1.4 COST ESTIMATES

The estimated costs for tracking and defining the uranium, technetium-99, and CCl_4 plumes over the next 200 years are about \$2.1 million, adjusted for inflation (\$21.1 million at 0% inflation). Table B-1 breaks out the costs per monitoring period. For this scoping evaluation, three time intervals were used for the estimates. The number of wells were held constant throughout each time interval. The first time interval/monitoring period includes those wells required to define the size of the plume at 50 years. So sampling costs were calculated for 75 wells for 50 years; i.e., from the present to 50 years. The number of wells was then increased by 30 for a total of 105 wells, and another 15 wells added for the final 100 years of monitoring (120 wells). The costs were then adjusted for a 4% inflation rate. Figures B-2, B-3, and B-4 show the monitoring networks for these periods.

Estimated sampling, laboratory, and coordination costs for a 75 well suite are $75,375 per sample event based on the current CERLCA program. For a 105 well suite the cost is $105,105 per sample event. And for 120 wells (the number of wells for the 200 year time period) the cost is $119,970 per sample event. The actual cost per sample decreases as the total number of samples increases. Table B-2 presents the costs for the 75 well suite, showing how the money is distributed for the different sampling tasks. Costs are given in 1997 dollars with no adjustment for inflation.

B2.0 CONCLUSIONS

It is estimated that groundwater monitoring costs to track the uranium, technetium-99, and CCl_4 contaminant plumes would cost about $2.1 million over the next 200 years (taking into account a 4% inflation rate). The CCl_4 plume is the primary cost driver, covering an area about 6 to 7 times greater than the uranium and technetium-99 plumes combined at the end of 200 years.

A more rigorous approach for estimating these costs would involve a geostatistical analysis and consideration of field screening analysis methods. A geostatistical analysis would aid in quantifying the number and location of monitoring wells. It is anticipated that both of these items will reduce the overall cost of monitoring.

One of the most significant assumptions in this study is that no new monitoring wells will be installed over the next 200 years. Based on general observation about the condition of groundwater wells installed in the 1940s, it appears that the life cycle of a well will not exceed 50 to 75 years. Most of the existing wells, particularly in the outer 600-Area are composed of carbon steel casing and screens (or more commonly perforations). A significant portion of the monitoring network may have to be replaced in the next 50 years. To refine the cost estimates, the life cycle of Hanford carbon steel wells could be determined. Well replacement costs could then be included in the estimate.

Figure B-1. Baseline Map Showing Hanford Site Groundwater Monitoring Wells and the Extent of the CCl_4 Plume at 50, 100, and 200 Year Time Slices. (Modified from BHI 1996)

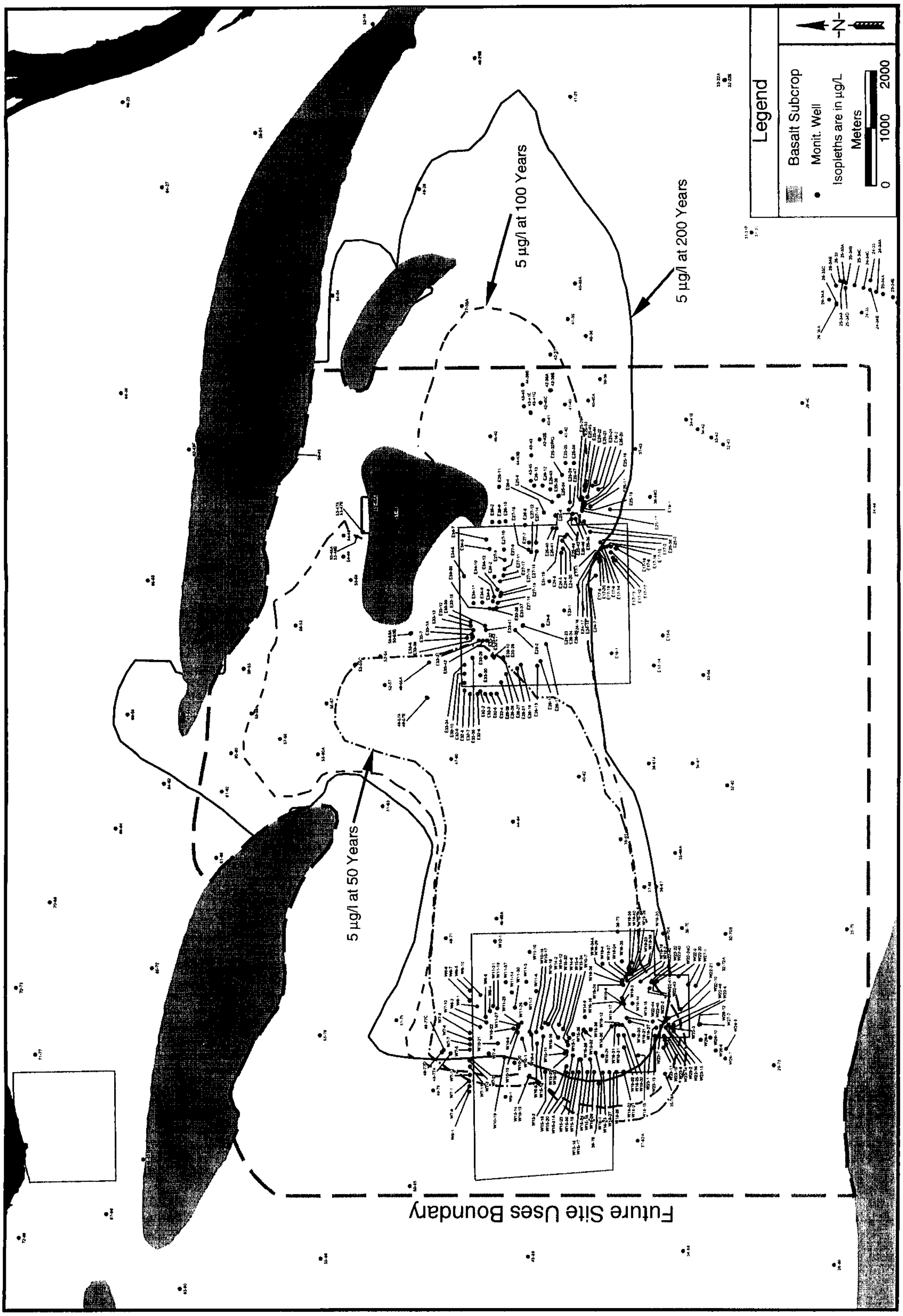

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Figure B-2. Extent of the CCl_4 Plume After 50, 100, and 200 Years and Associated Monitoring Networks for Tracking and Defining the Plume.

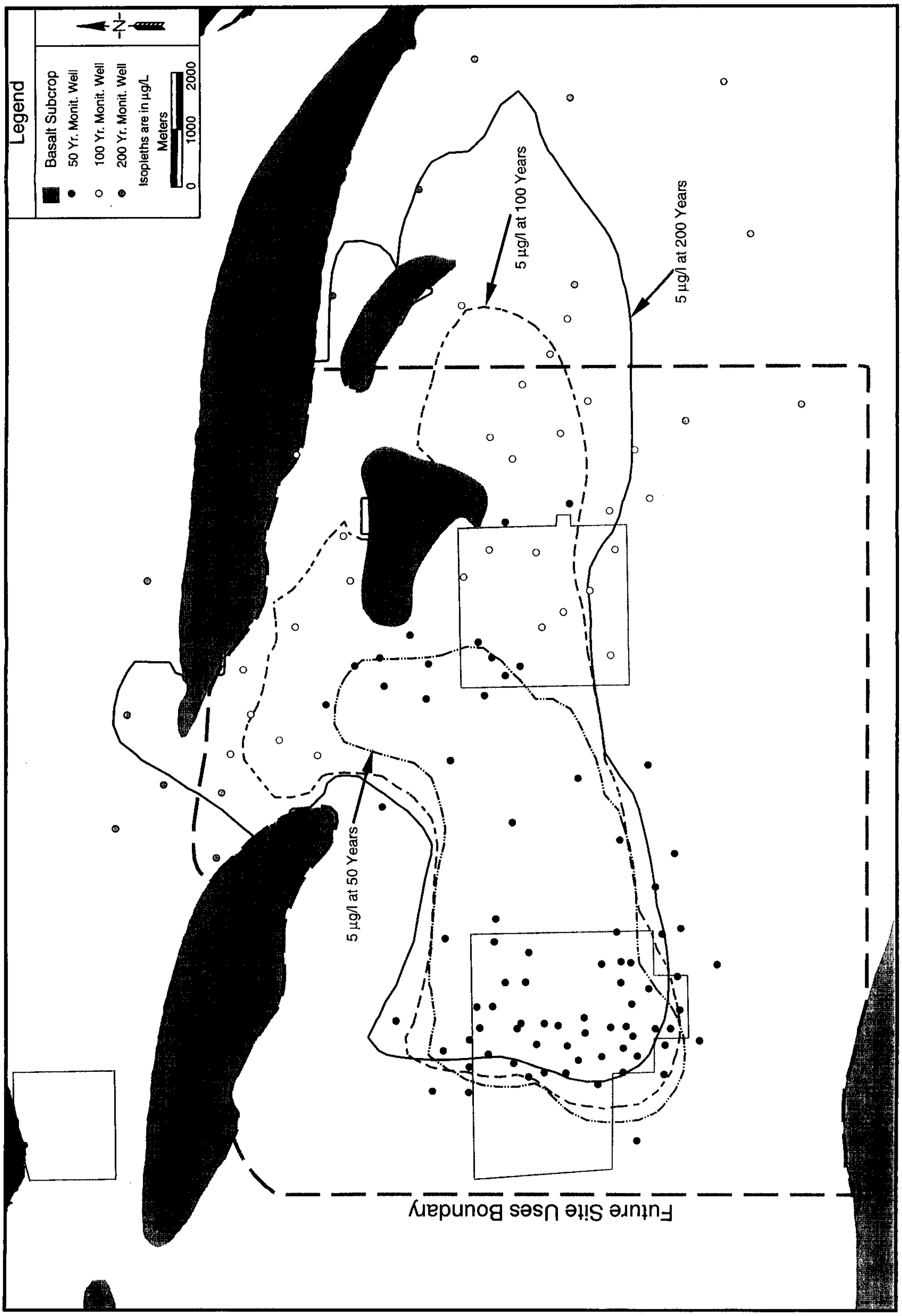

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Table B-1. Estimated Groundwater Sampling Costs for Tracking and Defining the Uranium, Technetium-99, and CCl_4 Plumes for the Next 200 Years.

Monitoring Period	Elapsed Time	Estimated Number of Wells	1997 Costs Per Monitoring Period	Costs Adjusted for Inflation[4]
50 Years	50 Years	75	$3,844,125[1]	$1,694,595
100 Years	50 Years	105	$5,255,250[2]	$317,713
200 Years	100 Years	120	$11,997,000[3]	$58,209
		Total Monitoring Costs	$21,096,375	$2,070,517

[1] Based on a cost of $75,375 for a 3-analyte suite and 75 wells.
[2] Based on a cost of $105,105 for a 3-analyte suite and 105 wells.
[3] Based on a cost of $119,970 for a 3-analyte suite and 120 wells.
[4] Assumed inflation rate of 4% per year.

Table B-2. Estimated Costs for Monitoring the Uranium, Technetium-99, and CCl_4 Plumes over the Next 200 Years for a 45-Well Monitoring Network.

Estimate of Sampling Costs

General Assumptions:
Analytes: Total U, Tc-99, and VOA
Method: Standard Lab procedures
Turn around time: 45 days
Data Package: Summary
Purgewater from all wells is contained

Specific Assumptions:

Number of Wells:	75
Assume number of sample suites:	75
Sampling Days:	30 (2.5 wells per day)
Analytical cost:	$28,875 ($385 per sample suite)
Collection costs:	$4,200 (2 persons at $70/hr for number of sampling days)
RCT coverage	$2,100 (1 person for half of the sampling day)
Purgewater dump:	$4,200 (2 hrs at $70/hr for number of sampling days)
Sample Management:	
- paperwork	$8,400 (4 hrs per sample day at $70/hr)
- shipping	$8,400 (4 hrs per sample day at $70/hr)
Initial Sample Coordination	$1,050 (15 hrs at $70/hr)
Follow up Coordination	$1,050 (.5 hrs per sample day at $70/hr)
Driver for purge truck	$14,400 (8 hrs at $60/hr per sample day)
Purge truck	$2,700 ($90/sample day)
Total Cost:	**$75,375**

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